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ORIGINAL ARTICLES.

I.—The Genesis of Tungsten Ores.

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THE exploitation of tungsten ores on a large scale is of comparatively recent development. Till lately the industrial applications of this metal and its compounds were very limited, and they were regarded rather in the light of chemical and mineralogical curiosities. In fact, the tungsten minerals were considered a nuisance by miners, owing to the difficulty of separating them from other valuable and equally heavy ores occurring in close association with them. Sodium tungstate was manufactured to a certain extent and used as a mordant in dyeing and for rendering textile fabrics fireproof, and tungstic oxide was sometimes employed in the making of yellow glass. About the year 1905 a demand arose for the metal for electric lamp filaments, but at the present time by far the most important application is in the metallurgy of steel. The addition of a small quantity of tungsten, not more than 7 or 8 per cent, together with about 5 per cent of chromium, has a remarkable effect on steel, rendering it both hard and tough and suitable for high-speed cutting tools. Since the beginning of the War the demand for the ores for this purpose has enormously increased, as also has the price; new sources are being sought for and opened up in many localities; in Colorado and California there was a few months ago a tungsten boom recalling the gold rushes of the early days. The resources of various parts of the British Empire are also being exploited on a large scale, and on its metallurgical side the tungsten industry is now very largely in British hands, whereas before the War Germany absorbed the greater part of the world's output of ore. Under present conditions it is naturally very difficult to obtain complete and reliable figures, but the following table (p. 194) shows approximately the output of tungsten ores throughout the world for the last few years. The figures (in tons) are taken from *The Mineral Industry*, vol. xxv, p. 741, 1916.

Although the following notes do not claim to contain the results of any original work, it is thought that a brief summary of our present knowledge of the genesis, mode of occurrence, and mineral associations of the tungsten ores may be of interest to geologists and mineralogists. The literature of the subject is widely scattered, largely in foreign publications, and the descriptions in most of the

standard textbooks are not very satisfactory. Mr. A. M. Finlayson[1] has briefly discussed the genesis of the ores from a theoretical point of view in the GEOLOGICAL MAGAZINE for 1910, giving a large number of references, and in 1909 the Imperial Institute published a small monograph on the subject from the practical standpoint,[2] but no general account of recent date seems to be available.

	1906.	1912.	1913.	1914.	1915.	1916.
United States . .	844	1,210	1,397	900	2,120	6,790
Argentina . .	300	638	539	394	171	700
Bolivia . . .	70	497	564	276	793	920
Peru . . .	—	214	300	196	371	400
England . . .	276	193	182	205	360	350
France . . .	20	230	245	200	200	200
Germany and Austria	60	167	150	220	250	300
Portugal . . .	570	1,330	800	967	1,400	1,600
Spain . . .	200	169	150	84	511	600
Burma . . .	—	1,905	1,732	1,868	2,883	4,123
Siam . . .	—	108	281	30	297	468
Japan . . .	40	205	297	195	439	1,150
Queensland . .	800	860	543	435	640	800
New South Wales .	271	271	209	220	100	146
New Zealand . .	165	165	270	250	249	300
World . .	4,000	8,780	10,000	8,000	12,000	19,000

The element tungsten does not enter into many compounds of natural occurrence. It belongs to the group of metallic elements that give rise to acid-forming oxides; tungstic acid forms salts with several divalent metals, especially iron, manganese, calcium, and lead. The tungstates of these metals fall into two well-defined groups; the iron and manganese minerals crystallize in the monoclinic system, while the others are tetragonal. So far as is known tungsten does not occur in nature as sulphides or anhydrous oxides; even the oxidation products of the tungstates are few in number, the only one that is at all common is tungstic ochre, a yellow powdery substance sometimes found as a crust on tungstate minerals. It appears to be a hydrated oxide or hydroxide of a not very definite composition. The tungstates are remarkably stable minerals, being little affected by any weathering agents, and in consequence the ores do not undergo secondary enrichment; on the other hand, they show a strong tendency to accumulate as shoad and alluvial deposits.

The iron and manganese tungstates, commonly known collectively to the miner as wolfram, form an excellent example of an isomorphous series. The two theoretical end-products are ferberite, $FeWO_4$, and

[1] Finlayson, "The Ore-bearing Pegmatites of Carrock Fell": GEOL. MAG., 1910, p. 19.

[2] "The Occurrence and Utilization of Tungsten Ores": Bull. Imp. Inst., vol. vii, pp. 170, 285, 1909.

hübnerite, $MnWO_4$. These two molecules may mix in any proportion. The varieties rich in manganese are perhaps the more common. Since every possible gradation of composition is known, it has been proposed by Messrs. Hess and Schaller [1] that arbitrary divisions shall be made as follows: all varieties with not more than 20 per cent of the manganese molecule are called ferberite and those with not more than 20 per cent of the iron molecule hübnerite, while intermediate varieties are called wolframite. In the following pages, however, the names wolfram or wolframite are used in the miner's sense to include all varieties of iron and manganese tungstates.

The tetragonal tungstates include scheelite, $CaWO_4$, and stolzite, $PbWO_4$. Of these the former is by far the more common and important. A new mineral from Northern Queensland, chillagite, is of interest, since it is an isomorphous mixture of the stolzite molecule, $PbWO_4$, and the wulfenite molecule, $PbMoO_4$, thus emphasizing the paragenetic connexion which undoubtedly exists between tungsten and molybdenum. The close mineralogical association between these two elements will appear later. Some varieties of both wolframite and scheelite contain a little copper, but this does not seem to be of much significance.

At this point it becomes necessary as a matter of convenience to anticipate somewhat and to state that the tungsten deposits can be most satisfactorily described under four headings, as follows:—

(*a*) Primary wolframite ores with cassiterite.
(*b*) Primary wolframite ores without cassiterite.
(*c*) Primary scheelite ores.
(*d*) Secondary (detrital) tungsten deposits.

The justification for this classification will appear in later sections of this paper.

Part I: Wolframite Ores with Cassiterite.

The tungsten ore deposits of the British Isles have lately been described very fully in a special memoir of the Geological Survey,[2] hence it is unnecessary to enter into a large amount of detail concerning them. In Cornwall the principal ore is wolframite, in Cumberland scheelite. The primary wolframite ores of Cornwall are of great interest from the theoretical point of view, since they afford an admirable example of the wolframite-cassiterite association. The primary ores of Cornwall are clearly of what is generally known as pneumatolytic origin, being associated with other minerals and rock-types characteristic of this phase of igneous action. It will, however, be pointed out in the general discussion of the genesis of these ores in a later section that the term pneumatolysis has been somewhat overworked in this connexion, and as commonly employed it really comprises two quite distinct classes of phenomena, or rather phases of igneous activity.

[1] "Colorado Ferberite and the Wolframite Series": Bull. 583, U.S. Geol. Surv., 1914, p. 37.

[2] *Special Reports on the Mineral Resources of Great Britain*, vol. i: *Tungsten and Manganese Ores* (Mem. Geol. Surv.), 1915.

The wolframite ores of Cornwall are always in association with granite intrusions; they occur in the granite itself, in pegmatite dykes, in lodes, and disseminated in a more or less irregular way in certain rocks in the immediate neighbourhood of the granite; the association with greisen is particularly close, and is of much genetic significance with regard to the mode of distribution of the ores.

It is quite clear that the pegmatite veins carrying wolfram are earlier than either the lodes in the country rock or the greisens. The list of minerals found in connexion with the wolfram ores is long, but the following are the most characteristic and significant: cassiterite, mispickel, chalcopyrite, tourmaline, topaz, and fluorspar. In the greisens of St. Michael's Mount and elsewhere uranium minerals also occur in association with wolfram.[1] The importance of this fact will be referred to again later. To sum up, the whole mineral association forms an excellent example of the tin-tungsten-fluorine paragenesis, which, as will be seen in the sequel, is so widely spread in many parts of the world.

In connexion with the tourmaline granites of Brittany wolframite is found along with cassiterite, molybdenite, mispickel, chalcopyrite, blende, and fluorspar. The ores occur in a network of veins (stockwork) in the granites, near their contact with mica-schists. The resemblance of this mineral assemblage to that found in Cornwall is obvious, and both evidently form part of one petrographical province from the point of view of the metallic contents of the magma, and both are characterized by the presence of fluorine and boron among the non-metallic constituents.

Although so far as is known the German resources of tungsten ores are but small, the occurrences are of considerable interest, and good descriptions have been published. The principal output is from the well-known mining district of the Erzgebirge in Saxony and Bohemia. The ancient crystalline rocks of the fractured district between Dippoldiswalde and Teplitz are penetrated by great masses of quartz-porphyry of Permian age (Teplitz quartz-porphyry); into this are intruded domes and bosses of granite of somewhat later date. The rocks surrounding the granite are highly mineralized, and in particular the quartz-porphyry, above the granite intrusions, is more or less converted into greisen and penetrated by innumerable veins and stringers carrying a great variety of ores. The districts richest in mineral veins are those of Altenberg, Zinnwald, Graupen, Ehrenfriedersdorf, Geyer, Eibenstock, and Johanngeorgenstadt. At Altenberg the ores occur in the form of a stockwork in the quartz-porphyry above the granite dome to the depth of about 750 feet. The mines of Zinnwald are said to be very rich in wolfram, and are also worked for lepidolite. Here the veins are in the quartz-porphyry and run parallel to the upper surface of the granite dome. The principal minerals are wolfram, scheelite, tinstone, arsenopyrite, galena, blende, chalcopyrite, tourmaline, topaz, and apatite. The impregnation with tin and other ores occurred before the last aplitic phase of the granite intrusion. At Ehrenfriedersdorf many tin-wolfram lodes of a similar type occur in mica-schist. The whole

[1] *The Geology of the Land's End District* (Mem. Geol. Surv.), 1907, p. 53.

mineralization here, as in Cornwall, is closely connected with the pneumatolytic phase of the Hercynian granite intrusions, and shows very clearly the genetic association of tungsten with tin and the highly volatile elements, fluorine, boron, and lithium.

Although the mines of the Erzgebirge in Saxony and Bohemia figure very largely in German mining literature and in textbooks, their yield of tungsten ores does not appear to be large, so far as is known. In 1912, the last year for which official statistics are available, the output for the kingdom of Saxony is stated to be 101 tons, while no other German state appears to have produced any. In the same year the Austrian Empire is said to have produced only 66 tons. It is believed that most of the wolfram ores were obtained by working over the old tin dumps. Nothing definite is known as to the extent of the supplies still available, but they are probably not very large. It is of course impossible to place great faith in the reliability of German statistics in connexion with any product connected with war preparations, but in this instance the figures may be correct, since in the years before the War Germany imported at least half of the world's total output of tungsten ores. Hence the reserves at hand were probably considerable.

Besides Great Britain the only other European producer of much importance is Portugal, although Spain also supplies a certain amount. In both these countries the ores are associated with cassiterite, belonging therefore to the group now under consideration. According to Granell[1] wolfram ores, usually accompanied by cassiterite, occur in a zone consisting of granite intruded into crystalline schists and Cambrian sediments, beginning in Galicia and extending through Northern Portugal, Zamora, Salamanca, and Caceres, and ending where it is cut off abruptly by the great Guadalquivir fault. There is also a similar mineral association in the mountain chains of Central Spain, in the province of Toledo, at Mijas near Málaga, and in the Almagrera Mountains; the latter was the locality of the original manganese-free ferberite, first described by Breithaupt. Little information is available as to the details of the wolframite ore-deposits of Spain and Portugal, but they do not seem to present any special features of interest, and a large part of the output is apparently alluvial. In the Sierra de Estrella in Portugal wolframite occurs in rich lodes up to 4 inches wide, associated with cassiterite and arsenopyrite.

In the Black Hills of Dakota wolframite occurs in two distinct genetic types:

1. With tinstone, as at Etta Knob and Nigger Hill.
2. With siliceous gold-ores.

The ore-deposit of Etta Knob is very remarkable, and in some ways unique. It consists of a vertical pipe of pegmatite some 60 yards in diameter, containing in addition to quartz, felspar, and mica also cassiterite, wolframite, molybdenite, arsenopyrite, tantalite, columbite, apatite, beryl, and spodumene, the latter in crystals over 30 feet long. The characteristic elements here are evidently tin, tungsten,

[1] Granell, Boll. Soc. Esp. Hist. Nat., vol. ix, p. 81, 1909, and Zeits. für Kryst., vol. l, p. 472, 1911.

tantalum, niobium, and lithium.[1] There are besides a great number of minerals of metamorphic origin, and pneumatolytic action seems here to have been very intense.

Somewhat similar to the foregoing is the well-known occurrence of cryolite at Ivigtut in Greenland, which also contains cassiterite and wolframite. The cryolite-bearing mass is about 500 feet long and from 100 to 180 feet wide, lying in granite, granite-porphyry, and gneiss. In the central portion of the mass cryolite predominates, with blende, galena, and chalcopyrite. The marginal portions, which are of pegmatitic character, consist of quartz, felspar, wolframite, cassiterite, molybdenite, and columbite. Fluorite is found in small quantity, but boron minerals are absent.[2] This mass must be regarded as a special facies of the tin-wolframite pegmatite, characterized by tantalum, niobium, and an enormous excess of fluorine.

Wolframite deposits occur on a large scale in a zone of country stretching from Tenasserim (Lower Burma) along the western side of the Malay Peninsula through Perak and Selangor. The Tavoy district of Burma and the Federated Malay States are now important producers; according to the latest statistics available Burma has now the second largest output of any country in the world.

In the Tavoy district[3] numerous granite masses are intruded into the sedimentary rocks of the Mergui Series. These, which are of unknown age, consist of quartzites, quartzitic conglomerates, and schists, the last being often graphitic. The igneous rocks, for the most part biotite granites, contain tourmaline and cassiterite as accessories. The wolfram lodes are quartz veins running out from the granites into the country rock; the chief minerals are quartz and wolframite, which alone occur in any large quantity. The other minerals present are cassiterite, molybdenite, arsenopyrite, chalcopyrite, bismuthite, galena, and tourmaline. A very characteristic feature is the almost universal occurrence of columbite. According to their mineral composition the lodes can be classified into three groups—

1. Wolframite-quartz lodes.
2. Cassiterite-quartz lodes.
3. Wolframite greisen.

Of these the first is by far the most important, the second and third groups being apparently rare, but the country is still very imperfectly explored.

From a generalization of the published descriptions of the Tavoy area it may be inferred that the mineral assemblage is specially characterized by wolframite, cassiterite, molybdenite, arsenopyrite, and columbite.

Little is apparently known of the intervening Siamese territory to the south of Tenasserim, although some ore is now exported, but the Federated Malay States are large producers of wolframite as well

[1] Hess, Bull. 380, U.S. Geol. Surv., 1909, p. 149.

[2] Ussing, Danmark Geol. Untersög., ser. II, No. 12, p. 97; Baldauf, Zeits. für prakt. Geol., vol. xviii, p. 432, 1910.

[3] Bleeck, Rec. Geol. Surv. India, vol. xliii, p. 48, 1913.

as of tin-ore, especially Perak and Selangor. The mining in these States, as in Burma, is very largely alluvial, but the minerals are also worked in situ in the granites. The tungsten occurrences have been well described by Mr. Scrivenor.[1] The prevailing rock is a biotite-hornblende granite, locally rich in tourmaline and cassiterite. The other minerals associated in the lodes are arsenopyrite, chalcopyrite, fluorspar, and topaz, with occasionally sapphire and thorium-cerium minerals. In Selangor the richest shoots of wolfram ore are generally found at the contact of granite and schist; where the lodes traverse the schists they contain fairly pure wolfram, on the contact they contain mixed ore, while within the granite they become richer in tin and poorer in wolfram. In this area scheelite deposits are also abundant, as will be described in a later section; the scheelite appears to be genetically connected with the wolfram lodes, and is probably derived also from the granitic magma under somewhat differing conditions.

The Seward Peninsula of Alaska affords an interesting example of a highly mineralized region of the type now being considered.[2] The country rock consists of quartzite, slate, and especially limestone of Palæozoic age, probably Carboniferous. These sediments are intruded by granite bosses and by quartz-porphyry dykes; the metamorphism thus produced is very intense, especially in the limestones, which contain many newly-formed minerals rich in boron and fluorine, such as tourmaline, axinite, danburite, vesuvianite containing boron, and other peculiar types.

Wolframite occurs in association with cassiterite in two different ways. On Cassiterite Creek the quartz-porphyry dykes intruded into the limestone are tin-bearing in depth. The tin-ore and wolframite occur as veins and stringers in the dykes, associated with arsenopyrite and pyrite. Blende and galena are less common, while molybdenite is local. The gangue minerals, besides quartz, are fluorite, topaz, and zinnwaldite. There are also cassiterite-wolfram lodes in the limestone; these lodes appear to be pegmatitic in origin, as they contain quartz, felspar and mica, fluorite and topaz; the other metallic minerals are chalcopyrite, pyrrhotite, blende, and galena.

Another remarkable occurrence is a wolframite-topaz lode, with galena and stannite, on Lost River. The gangue consists of purple fluorite and radial topaz. The presence of some silver is shown by assays.

From the chemical point of view the most striking feature of this region is the abundance of boron, which has led to the formation of many minerals containing that element, of which the most interesting are paigeite and hulsite, two new iron-magnesia-tin-boron minerals. In this region boron seems to be in excess of fluorine, an unusual occurrence.

The wolframite output of Queensland comes from the northern

[1] Paper on Tungsten Ores, read before the F.M.S. Chamber of Mines at Ipoh, March 25, 1916 (no place of publication or date).

[2] "The Geology of the Seward Peninsula Tin Deposits," by A. Knopf, Bull. 358, U.S. Geol. Surv., 1908.

part of the colony, from the Herberton tin-field, from the Etheridge mineral field, from Mount Carbine, Bamford, and other areas. In the Herberton district the country rock consists of highly metamorphosed sediments, including quartzite, greywacke, and shales, intruded by biotite and hornblende granite, quartz porphyry, and felsite. Lodes occur in all of these, containing a considerable variety of minerals, including cassiterite, wolframite, bismuthine, antimonite, chalcopyrite, galena, magnetite, tourmaline, topaz, and fluorspar. In the Hodgkinson field wolframite and molybdenite occur in quartz veins in a grey biotite granite. At Mount Carbine slates and schists are penetrated by batholiths of porphyritic biotite-granite. In connexion with this are pegmatite dykes and interlacing veins forming lodes up to 6 feet wide. The pegmatites consist of quartz-felspar rock with tourmaline, some muscovite, and a little beryl. The metallic minerals are cassiterite, wolframite, arsenopyrite, and molybdenite. The wolframite appears to be more closely connected with the felspar than with the quartz. One block of wolframite was found weighing 6 tons. There is also some scheelite.

In the Bamford district the rocks are mainly igneous, both volcanic and intrusive. Wolframite occurs as an original constituent in biotite-granite, and also in pegmatites and greisens in connexion with the granite. A large number of minerals has been observed here; the chief are: wolframite, bismuth (both native and as sulphides, carbonates, and oxides), molybdenite, pyrite, chalcopyrite, blende, and galena; cassiterite has been found, but it is not very common. Of much interest also are ilsemannite, stolzite, and the new mineral chillagite, previously mentioned as an isomorphous mixture of lead tungstate and lead molybdate. The ore-deposits are mainly in the form of pipes of white quartz, with wolframite and molybdenite; vugs are seen up to 20 feet in diameter, containing bismuth, fluorite, and some sulphides; the smaller vugs are rich in wolfram, while the larger ones are poor. These vugs are possibly due to stoping along fissures. Although the form of the wolfram pipes is somewhat unusual, they do not differ in any essential feature from the common type of wolfram-molybdenite pegmatites formed by solidification of the last residues of a granitic magma in which these elements have been segregated by differentiation or concentration, whichever word is preferred in this connexion.

From the published descriptions of the Queensland mines it appears that a large proportion of the present output comes from shoad deposits, which are locally described as alluvial. This material does not appear, however, as a rule to have been transported for any distance, but rather to be a true residual deposit.

Wolframite is also found in the tin area of Mount Bischoff in Tasmania. Here quartz-porphyry dykes, intruded into Palæozoic sediments, have undergone intense pneumatolytic metamorphism, being largely replaced by secondary minerals, including cassiterite, wolframite, arsenopyrite, pyrrhotite, tourmaline, topaz, and fluorite. Perhaps the most striking feature here is the great development of topaz in the altered dykes.

The extraordinarily rich lodes of the provinces of Oruro and Potosi

in Bolivia have long been worked on a very large scale for tin and silver, but lately there has been a great development of wolfram mining in this area. In 1916 a very active tungsten boom began in Bolivia, as elsewhere, and the output is now very large. The lodes are connected with masses of rhyolite and dacite, these being of the nature of laccolithic intrusions rather than flows. The gangue minerals are quartz, barytes, and carbonates; the ores in depth are mainly sulphides, together with cassiterite and wolframite. The metals present in the form of sulphides are iron, lead, zinc, copper, antimony, bismuth, and silver; tin sulphide (stannite) is also found, and in the gossan it has been converted into wood-tin. Original cassiterite and wolframite represent the primary oxidic ores, but in the gossan there are many oxidized minerals, as well as native silver and silver chloride in great quantities. Of special interest are three minerals, argyrodite, franckeite, and canfieldite, containing the exceedingly rare element germanium. It is evident, therefore, that the tin-wolfram lodes of Bolivia form an aberrant and in some respects transitional type; fluorite and tourmaline certainly do occur, but they are quite rare, and pneumatolytic minerals are for the most part absent. The whole mineral association shows a much closer approach to the sulphide type than is usual in tin-bearing deposits.

The tin-wolfram veins of Mexico (Durango, Guanajuato, and San Luis Potosi) show some affinity to those of Bolivia; they are associated with rhyolites, and the principal minerals in addition to cassiterite and wolframite are native bismuth, specular iron-ore, and durangite (a sodium-aluminium arsenate with fluorine). Topaz is found, but no tourmaline. These veins appear to be of very recent date. In this case there are no sulphides, and it is perhaps permissible to regard them as an ultra-oxidic type, specially characterized by fluorine. The relationship to other types of tin-wolfram ores is not clear.

Summary of Part I.

A careful consideration of the facts set forth in the foregoing pages shows that the ore-deposits of the wolframite-cassiterite type result directly from the cooling of granitic magmas, and the metals, tin and tungsten, are integral and characteristic constituents of those magmas. In many instances cassiterite is known to occur as a primary constituent of the granite; less commonly wolframite is found in a similar way. As a rule, however, these minerals become concentrated in that fraction which is highly volatile and escapes from the central portions of the intrusion, forming pegmatites and greisens in the granite itself and in the surrounding rocks. This tendency is doubtless accounted for by the fact that both tin and tungsten form highly volatile compounds with fluorine. The formation of cassiterite by the action of water on tin fluoride was long ago experimentally verified by Daubrée. According to Roscoe and Schorlemmer, tungsten hexafluoride is a gas at temperatures above 19° C. under normal pressure. All the evidence from the relative distribution of cassiterite and wolframite in lodes, goes to show that the latter is more volatile than the former, since it usually travels further from the margin of the granite; tin-wolfram lodes pass laterally

and continuously into wolfram lodes and these again into pure quartz veins.

When the distribution of these minerals is studied in detail it is seen that the original metallic minerals of the granites and the ore-minerals of the pegmatites, greisens, and quartz lodes are of common genesis. They all arise as products of the crystallization of the differentiated magma. There is, therefore, in this case, no real distinction between magmatic segregations and vein-deposits. Consequently, the classification so prevalent in German textbooks into syngenetic and epigenetic deposits here breaks down. The difference is mainly one of time, or as it may be otherwise expressed, a difference of phase.

The formation of these deposits, then, may be summarized as follows:—

1st phase: Concentration within the magma of the metallic constituents in combination with the volatile elements, especially fluorine and boron.

2nd phase: Separation from the crystallizing granite of the compounds thus formed, and escape of the same through fissures.

3rd phase: Chemical reactions between the compounds in the escaping gases or solutions, leading to the formation of crystallized ore and gangue minerals.

It is, of course, impossible to draw any hard and fast line between these different phases; they are all parts of one continuous process, and in many instances doubtless proceed concurrently.

Turning now to the mineralogical and chemical side of the question, we find a marked similarity of composition in all parts of the world. Although there are local differences in detail, yet it is possible to enumerate certain minerals of almost universal occurrence in association with wolframite and cassiterite. Of these the most characteristic among the sulphides are arsenopyrite and molybdenite. Chalcopyrite again is common, while blende and galena are more sporadic. Of the non-metallic minerals, tourmaline, topaz, and fluorite are characteristic, showing the presence of the highly volatile and chemically active elements fluorine and boron.

Special interest attaches to the presence in certain localities only of notable amounts of some of the rarer elements, such as niobium, tantalum, and uranium. The last, for example, is found in Cornwall, while columbite is abundant in Burma and in the extraordinary pegmatitic masses of Etta Knob and Ivigtut. At Etta Knob it is accompanied by a striking development of lithium minerals. In Bolivia silver is the most characteristic element. From these and similar considerations it appears possible to subdivide the tin-tungsten occurrences into paragenetic sub-types, as follows:—

Tungsten, tin	molybdenum, arsenic	uranium . .	Cornwall.
		tantalum and niobium	Burma, Etta Knob, Ivigtut.
		bismuth . .	Queensland.
	silver	germanium .	Bolivia.

Furthermore, with respect to the non-metallic elements, some regions are characterized by excess of fluorine, others by excess of boron, each giving rise to characteristic groups of minerals, which indicate the chemical composition of the original magma. The further significance of these facts will be discussed more fully at a later stage.

The following table shows the chief minerals found in ten of the more important wolfram-tin ore-deposits in different parts of the world :—

	Cornwall.	Brittany.	Erzgebirge.	Dakota.	Greenland.	Burma.	Malay States.	Alaska.	Queensland.	Tasmania.
Wolframite	x	x	x	x	x	x	x	x	x	x
Cassiterite	x	x	x	x	x	x	x	x	x	x
Molybdenite	—	x	—	x	x	x	—	—	x	x
Arsenopyrite	x	x	x	x	—	x	x	x	x	x
Chalcopyrite	x	x	x	—	x	x	x	x	x	x
Galena	x	—	x	x	x	x	—	x	x	—
Blende	x	x	x	—	x	—	—	x	x	—
Pyrite	x	—	—	—	x	—	—	x	—	x
Bismuth minerals	—	—	—	x	—	x	—	—	x	—
Uranium ,,	x	—	x	—	—	—	—	—	—	—
Columbite	—	—	—	x	x	x	—	—	—	—
Tourmaline	x	x	x	x	—	x	x	x	x	x
Fluorite	x	x	—	—	x	—	x	x	x	x
Topaz	x	—	x	—	—	—	x	x	x	x

(*To be continued.*)

II.—Foraminiferal and Nullipore Structures in some Tertiary Limestones from New Guinea.

By R. Bullen Newton, F.G.S., Geological Department, British Museum.[1]

(PLATES VIII AND IX.)

Introduction.

At the request of Professor J. W. Gregory, F.R.S., of Glasgow University, the following report has been prepared dealing with some microscopical organisms entering into the composition of certain limestones from Central New Guinea. The material studied, comprising Foraminifera and Nullipore (*Lithothamnium*) remains, has been obtained from some rolled limestone pebbles which were collected in river-beds of the upper reaches of the Fly River by the Right Hon. Sir William Macgregor, G.C.M.G., during an expedition carried out in the years 1889 and 1890. Being desirous that these limestones should be scientifically examined, Sir William submitted them to the Geological Department of the University

[1] Published by permission of the Trustees of the British Museum.

Glasgow in the hope that Professor Gregory and his staff might issue a statement as to their structural and geological value. In accordance with this request, therefore, the corals were first examined and described in a joint paper by Professor Gregory and Miss J. B. Trench,[1] while some remarks on the Foraminifera and associated structures have been postponed for the present occasion. At the time when the corals were in course of description, the writer was appealed to for an opinion as to the geological age of one of the pebbles (No. 1), exhibiting corals and some smaller organisms, although to give aid in this direction it was necessary to prepare microscopical sections of the limestone for examination by transmitted light. It was then ascertained that the genus *Alveolina* was of frequent occurrence, as well as other Foraminifera, chiefly of the Milioline group. According to Orbigny,[2] *Alveolina* originated in Cretaceous times, having been recorded from the Cenomanian rocks of France; it is, however, much more typical of the Eocene period, being well known in deposits of that age as developed in England (Bracklesham Beds particularly), Europe, Egypt, Madagascar, India, Java, Celebes, New Guinea, etc. The genus is less abundant in the younger Tertiary formations, while according to H. B. Brady[3] two species alone survive in tropical seas at the present day. The distribution of this genus, therefore, and its association in the limestone pebble with the Miliolines, so characteristic of the Bracklesham Beds and corresponding deposits of the Paris Basin, suggested that the pebble might be attributed to the Lutetian or Middle division of the Eocene series, a result since accepted and published in the Gregory and Trench paper previously referred to (p. 532).

Bibliography.

Several memoirs have been issued on the organic structures of New Guinea Tertiary rocks, most of which have been recently reviewed in a paper by the writer,[4] and although it is unnecessary to repeat such information it seems desirable to refer again to that part of the literature which more particularly concerns the occurrence of *Alveolina* in that country. The first mention of *Alveolina* in the limestones of New Guinea was made by Dr. K. Martin[5] in 1881, from material obtained in north-west regions, the generic determination having been confirmed by Schwager, who, moreover, considered that the specimens were related to *A. spherica* (Fortis), the equivalent of *A. melo* (Fichtel & Moll), a characteristic Miocene species, besides being known from older Tertiaries as well as from recent seas. The

[1] "Eocene Corals from the Fly River, Central New Guinea": Geol. Mag., 1916, pp. 481–8, 529–36, Pls. XIX–XXII.

[2] Prodrome Pal. Strat., 1850, vol. ii, p. 185.

[3] *Rep. Voy. H.M.S. "Challenger": Zoology—Foraminifera*, vol. ix, pl. xvii, figs. 7–15, pp. 221–4, 1884.

[4] R. B. Newton, "Notes on some Organic Limestones, etc., collected by the Wollaston Expedition in Dutch New Guinea, from Reports on the Collections made by the British Ornithologists' Union Expedition and the Wollaston Expedition in Dutch New Guinea (1910–13)": Report No. 20, vol. ii, 1916.

[5] "Eine Tertiaerformation von Neu-Guinea und benachbarten Insel": Samml. Geol. Reichs.-Mus. Leiden, vol. i, pl. iii, figs. 9–10, p. 70, 1881.

organism was briefly described and figured as *Alveolina* sp., and was said to be associated with Orbitoides, *Cycloclypeus*, etc., and the Nullipore *Lithothamnium* (*Cumulipora*) *rosenbergi*, Martin, now better known as *L. ramosissimum* of Reuss, which is typical of Miocene rocks.[1] The Orbitoides were stated to possess rectangular chamberlets (*rechteckige mediankammern*), as seen on the median plane, thus implying the presence of the Eocene genus *Orthophragmina*. It is evident that some confusion must have arisen with the material determined by Martin to account for such an assemblage of forms, and it seems fair to suggest that the *Alveolina* and the Orbitoides belonged to an Eocene limestone, while the remaining organisms, *Cycloclypeus*, *Lithothamnium*, etc., indicative of a Miocene origin, were, in all probability, observed in another rock. Martin first of all determined this limestone as Tertiary, although a year later[2] definitely placed it in the older Miocene and in correlation with similar deposits of Indo-Pacific countries.

In his 1881 memoir, Martin likewise referred to certain limestones he had examined from Geelvink Bay localities and from islands off the south-western end of New Guinea, mostly containing Orbitoides, a small *Nummulina* sp., and *Lithothamnium rosenbergi*. They were regarded as of Tertiary age, with a resemblance to the older Miocene rocks of Timor, Java, and Sumatra. The Orbitoides were stated to belong to the Lepidocycline group of the type of *O. gigantea* of Martin, from the Miocene of Java.

Schlumberger subsequently studied the same material as described by Martin containing the so-called *Alveolina* sp., which had been submitted to him by Dr. Wichmann.[3] He was unable to recognize the accuracy of Martin's *Alveolina*, but regarded the organism as presenting structures belonging to the genus *Lacazina* of Munier-Chalmas; he therefore described and figured it under the new specific designation of *L. wichmanni*. The author also remarked on the interest of the discovery since *Lacazina* had hitherto been restricted to the younger Cretaceous rocks of Europe and Palestine, and now, according to Martin's interpretation as to the age of the New Guinea deposits, this genus could be recognized as occurring in the Tertiaries of that region. Schlumberger also mentioned that the associated Foraminifera included Rotalinæ, Miliolidæ, and a true *Alveolina* of the sub-genus *Flosculina*. Moreover, he had not seen the assemblage of forms referred to by Schwager (in Martin), the determinations of which he considered as of doubtful value.

Martin[4] next identified the presence of *Lacazina wichmanni* in some detrital limestones from south-west New Guinea (Setakwa River, etc.)

[1] R. B. Newton & R. Holland, "On some Fossils from the Island of Formosa, etc.": Journ. Coll. Sci. Imp. Univ. Tokyo, Japan, vol. xvii, art. 6, pl. i, fig. 8, pp. 17–19, 1902.

[2] "Neue Fundpunkte von Tertiaergesteinen im Indischen Archipel": Samml. Geol. Reichs.-Mus. Leiden, vol. i, p. 178, 1882.

[3] "Note sur *Lacazina wichmanni*, Schlumberger, n.sp.": Bull. Soc. Géol. France, ser. III, vol. xxii, pl. xii, pp. 295–8, 1894.

[4] "Paläozoische, Mesozoische, und Känozoische Sedimente aus dem südwestlichen Neu-Guinea": Samml. Geol. Reichs.-Mus. Leiden, vol. ix, pp. 84–107, 1911.

associated with *Alveolina* and *Nummulina*, and on account of its frequent occurrence he named the limestones "Lacazinenkalk" and considered them as of Eocene age. On the same occasion Martin also referred to the discovery of *Alveolina* by Dr. H. A. Lorentz in the limestones of Mt. Wilhelmina, situated in south-central Dutch territory at an altitude of more than 13,000 feet or 4,461 metres. The genus was found accompanying Nummulites, and in consequence ascribed to the Eocene period.[1] A still further reference occurs in Martin's memoir regarding *Alveolina*, mention being made of its identification in the limestones of Digoel River (S.W. New Guinea) associated with *Lepidocyclina* and *Lithothamnium* and stated to belong to the older Miocene.

The latest notice of importance respecting the occurrence of *Alveolina* in New Guinea is to be found in a report by Dr. L. Rutten,[2] published in 1914, containing figures and description of a new species, *A. wichmanni*, from the Eocene limestones of Dramai Island, Triton Bay, south-west New Guinea, which is stated to have been associated with *Lacazina wichmanni*, Schlumberger. The palæontology of the older Miocene limestones of New Guinea has rather recently been studied, and quite independently, by Mr. F. Chapman,[3] of the National Museum, Melbourne, and the present writer,[4] with very similar results. The principal organisms recognized were various species of *Lepidocyclina*, *Cycloclypeus*, *Carpenteria*, *Lithothamnium ramosissimum*, etc., an assemblage indicative of the Upper Aquitanian, which represents the oldest stage of the Miocene formation.

The Limestone Pebbles.

The pebbles submitted for examination are numbered 1, 2, 11, 12, and 28, the largest being Nos. 1 (90 × 50 mm.) and 2 (105 × 60 mm.), whereas the others are, roughly, about a third of their size. They consist of slightly different-coloured limestones, which in connexion with their organic contents are considered to belong to two different Tertiary horizons: the Eocene and the Miocene. Being rounded and of water-worn character, they may be termed rolled-limestone pebbles; and further, having been collected from river-beds in the upper reaches of the Fly River, their origin undoubtedly points to the great limestone development which, as high mountain ranges, runs east and west through the wide central region of New Guinea.

[1] For some unexplained reason this limestone from Mt. Wilhelmina with *Alveolina* has been rather recently determined as of Cretaceous age in an article on "Papua" contained in the *Federal Handbook*, prepared for the 84th Meeting of the British Association for the Advancement of Science, held in Australia, 1914, pp. 256, 321.

[2] "Foraminiferen-Fuhrende Gesteine von Niederländisch Neu-Guinea": A. Wichmann's *Nova Guinea*, vol. vi, "Géologie," livr. ii, pl. ix, figs. 1, 2, p. 45, 1914.

[3] "Description of a Limestone of Lower Miocene age from Bootless Inlet, Papua": Journ. Proc. Roy. Soc. New South Wales, vol. xlviii, pt. ii, pls. vii–ix, pp. 281–301, 1914.

[4] R. B. Newton, the Wollaston Expedition Report, 1916, previously alluded to.

No. 1. This consists of a cream-coloured limestone of one uniform tint throughout, and is that previously determined by the writer for Professor Gregory as exhibiting *Alveolina*, Miliolines, and coral structures, and which was referred to the Middle and Lutetian stage of the Eocene period. A further examination of this pebble has now furnished evidence of the presence of *Lacazina* and *Orthophragmina*, so that its geological age seems to be beyond question and, moreover, it fairly closely corresponds with the "Mixen" and "Clibs" rocks of Bracklesham Bay, England, and the "Miliolite" Limestone of the Paris Basin, all of which contain *Alveolina* associated with Miliolines, and which belong as well to this stage of the Eocene Series.

No. 2. A cream-coloured limestone, but with deep reddish-brown veins extending to the centre of the pebble. It contains occasional *Alveolina*, Corals, and an abundance of the Nullipore, *Lithothamnium ramosissimum*, whilst the absence of Miliolines and Lepidocyclines may also be noted. Chiefly from the occurrence of the Nullipore, so peculiarly characteristic of the Miocene limestones of Europe and Far Eastern countries, this pebble is regarded as belonging to that division of the Tertiary system.

No. 11. Is cream-coloured, but intersected by thin dark veinings. It resembles No. 1 in possessing similar coral structures, of which it is mainly composed. Miliolines are also present, the polished surface exhibiting a transverse section of *Pentellina* like *saxorum*. No Alveolines are discernible, but the assemblage denotes an Eocene origin for this pebble.

No. 12. A yellowish cream-coloured limestone containing Miliolines, *Textularia*, *Carpenteria conoidea*, etc., and *Lithothamnium ramosissimum*, the latter suggestive of its Miocene age.

No. 28. This is mainly composed of a stellate coral structure, although its narrower end reveals some minute Foraminifera, especially an Alveoliniform-looking organism, occurring as transverse and longitudinal sections on the polished surface, which represents *Lacazina wichmanni*, a New Guinea fossil of known Eocene age.

Organisms contained in the Pebbles.

FORAMINIFERA.

ALVEOLINA WICHMANNI, Rutten. (Pl. VIII, Figs. 1*a*, 2*a*, 3, 4*a*, 5, 6.)

Alveolina wichmanni, Rutten, Wichmann's *Nova Guinea*, vol. vi, "Géologie," pt. ii, pl. ix, figs. 1, 2, p. 45, 1914; Samml. Geol. Reichs.-Mus. Leiden, ser. 1, vol. ix, pl. xxvi, figs. 3, 4, and pl. xxvii, fig. 2, pp. 315–18, 1914.

This is an Eocene species having been originally described from the limestones of south-west New Guinea (Triton Bay) and afterwards from the Island of Celebes. It presents a narrow, tapering, and spindle-shaped axis composed of few and often irregularly formed layers which vary in number from nine to fourteen. Those forms with more regularly disposed layers are represented by Figs. 3 and 4*a*, whereas Figs. 1*a* and 2*a* show a greater irregularity and thus more closely approach the type. A transverse section displayed on the polished surface of the pebble, Fig. 6, exhibits a series of

apertures which represent the longitudinal channels that perforate the organism throughout its longer axis. A good longitudinal view of a weathered specimen exposing a partial interior is illustrated by Fig. 5, in which the margins of the layers are to be observed together with the closely set, external, transverse striations. Miliolines of the Quinqueloculine type and other Foraminifera accompany this species, see Figs. 1*b*, 2*b*, and 4*b* of Plate VIII.

Dimensions.—Length 3–8, width 1–2½ mm.

Occurrence.—Pebble No. 1.

Distribution.—Eocene deposits of New Guinea and the Island of Celebes.

ALVEOLINA sp. (Pl. IX, Fig. 6*a*.)

A longitudinal section of this genus occurs in No. 2 pebble associated with *Lithothamnium ramosissimum*. It is rounded at the poles and not fusiform as is the case in *A. wichmanni*, being most nearly related to *A. melo* (Fichtel & Moll), which, according to Brady,[1] ranges from Eocene to Recent seas. The presence of the Nullipore in this pebble strongly supports its Miocene origin.

Dimensions.—1 by ½ mm.

Occurrence.—Pebble No. 2.

LACAZINA WICHMANNI, Schlumberger. (Pl. IX, Figs. 1, 2, 3*a*.)

Alveolina sp., cf. *A. spherica* (Fortis), Martin & Schwager: Samml. Geol. Reichs.-Mus. Leiden, vol. i, pp. 70–83, pl. iii, figs. 9–10, 1881.

Lacazina wichmanni, Schlumberger, Bull. Soc. Géol. France, ser. III, vol. xxii, pl. xii, pp. 295–8, 1894; Rutten, Wichmann's *Nova Guinea*, vol. vi, "Géologie," pt. ii, pl. viii, figs. 8, 9, p. 44, 1914.

The form here referred to is of frequent occurrence in No. 1 pebble, and is also found in No. 28 pebble accompanying a stellate coral structure. Specimens showing both longitudinal and transverse sections are well exposed on the polished surfaces of the limestones, and they resemble Martin's figures of *Alveolina* sp. found in the north-west coastal regions of New Guinea, which was determined by Schwager as being related to *A. spherica* (Fortis), the equivalent of *A. melo* (Fichtel & Moll), a characteristic Miocene species. At a later date, however, Schlumberger studied Martin's material and recognized the supposed *Alveolina* sp. as a new species of *Lacazina*, Munier-Chalmas (Bull. Soc. Géol. France, ser. III, vol. x, p. 472, 1882, type = *Alveolina compressa*, Orbigny), a genus hitherto restricted to the younger Cretaceous rocks of Europe and Palestine.

The chief features of interest respecting *L. wichmanni* are its possession of a spherical initial chamber succeeded by chambers the walls of which are alternately open below and above the poles throughout its growth. The chambers are also divided internally by numerous longitudinal ribs radiating from the external wall of each chamber and often appearing to reach the inner surface of the succeeding layer. These characters are more or less expressed in the present examples, although the delicate openings of the chamber walls are most difficult to trace, and their existence is only obscurely indicated. The radio-longitudinal ribbing appears also to be finer

[1] *Challenger Report: Foraminifera*, 1884, pl. xvii, figs. 13–15, p. 223.

than in Schlumberger's illustrations, but if our figures are subjected to a higher magnification a coarser effect is produced which yields a considerable resemblance to the type. First regarded as Tertiary, then Miocene, Martin[1] finally admitted this organism as of Eocene age, more particularly as it was now known to have been found with *Nummulites* in the rocks of south-western New Guinea (Setakwa River). On account of its great frequency in the limestones of New Guinea, Martin established the name *Lacazinenkalk*. Miliolines are in close association with this genus, forms being clearly depicted in Fig. 3*b* of Plate IX.

Dimensions.—From 1 to 4 mm. in diameter.

Occurrence.—In pebbles Nos. 1 and 28.

Distribution.—Species found only in New Guinea rocks.

ORTHOPHRAGMINA sp. (Pl. IX, Fig. 4.)

A fragmentary example of this genus is to be observed on the polished surface of No. 1 pebble. It is merely a portion of a horizontal section measuring about 8 mm. across the disc, exhibiting remains of eight or nine of the later annulations which enclose numerous rectangular chamberlets characteristic of *Orthophragmina*, an Eocene genus founded by Munier-Chalmas[2] in 1891, on the type of Michelin's *Orbitolites pratti*, from the Eocene of Biarritz, France.

From this single imperfect specimen and with no knowledge of its embryonic characters, it is not possible to venture on a specific determination. Nevertheless, so far as the evidence goes, it may be stated to show resemblances to the published figures of *O. pratti*,[3] which includes Gümbel's *Orbitoides* (*Discocyclina*) *papyracea*, *non* Boubée,[4] an Eocene form of Europe and other countries.

Occurrence.—Pebble No. 1; associated with *Alveolina*, *Lacazina*, Miliolines, etc.

CARPENTERIA CONOIDEA, Rutten. (Pl. IX, Fig. 5.)

Carpenteria conoidea, Rutten, Wichmann's *Nova Guinea*, vol. vi, "Géologie," pt. ii, pl. vii, figs. 6–9, p. 47, 1914.

Dr. Rutten has described an erect form of *Carpenteria* from the older Miocene deposits of northern New Guinea to which the present specimen may be referred. The fossil in question is the large central organism represented in Fig. 5, in which is displayed a longitudinal view of the interior showing a segmental structure composed of thick and porous walls, and a well-marked conoid-apical region, from which succeeds its later development widening appreciably to the base. The chambers, especially those observed near the base, are of crescentic form resembling *Globigerina*.

[1] "Paläozoische, Mesozoische, und Känozoische Sedimente südwestlichen Neu-Guinea": Samml. Geol. Reichs.-Mus. Leiden, vol. ix, p. 104, 1911.

[2] *Etude du Tithonique, du Crétacé, et du Tertiaire du Vicentin*, 1891, Thèse de doctorat, p. 18.

[3] Schlumberger, Bull. Soc. Géol. France, ser. IV, vol. iii, pls. viii, ix, p. 274, 1903.

[4] Gümbel, *Beitrage zur Foraminiferen der Nordalpinen Eocängebilde*, 1868, pl. iii, fig. 1, p. 112.

This organism is associated with *Textularia, Quinqueloculinæ*, etc., and *Lithothamnium ramosissimum*, the presence of the latter more particularly suggesting a Miocene origin.

Dimensions.—Length 2, width 1 mm.

Occurrence.—Found in No. 12 pebble.

Distribution.—Known only in the Miocene rocks of New Guinea.

MILIOLINES. (Pl. VIII, Figs. 1*b*, 2*b*, 4*b*; Pl. IX, Fig. 3*b*.)

Milioline Foraminifera associated with *Alveolina*, *Lacazina*, etc., are abundant in No. 1 Pebble. The more striking form, as seen in the sections and represented by our photographic figures, exhibits transversely plicated chamber walls, thus suggesting a relationship to *Pentellina saxorum* (Orbigny), a fossil of frequent occurrence in the Miliolitic Limestone of Paris and the "Clibs" and "Mixen" rocks of the Bracklesham Beds of England, all of which belong to the Lutetian or Middle Eocene horizon.

It is interesting to note that Miliolines with similarly associated forms have been reported from the Eocene limestones of the Island of Celebes by Dr. Rutten.[1]

Dimensions.—1½ mm. in diameter.

Occurrence.—In No. 1 pebble.

PLANTÆ (NULLIPORE).

LITHOTHAMNIUM RAMOSISSIMUM, Reuss. (Pl. IX, Figs. 6*b*, 7.)

Nullipora ramosissima, Reuss, Nat. Abhandl. Haidinger, vol. ii, pt. i, pl. iii, figs. 10, 11, p. 29, 1848.

Lithothamnium ramosissimum, Gümbel, Abhandl. k. bayerischen Akad. Wiss. München, vol. xi, pt. i, pl. i, fig. 1, p. 34, 1871.

Cumulipora rosenbergi, Martin, Samml. Geol. Reichs.-Mus. Leiden, vol. i, pp. 12 14, 64, pl. iii, fig. 7, 1881.

Lithothamnium ramosissimum, Nishiwada, Journ. Coll. Sci. Imp. Univ. Tokyo, vol. vii, pt. iii, p. 236, pl. xxix, figs. 1–4, 1894.

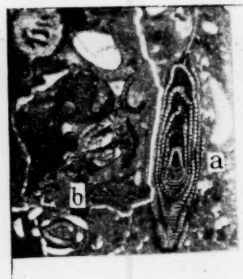
L. (*Cumulipora*) *rosenbergi*, Newton & Holland, Journ. Geol. Soc. Tokyo, vol. vii, No. 81, p. 22, 1900.

L. ramosissimum, Newton & Holland, Journ. Coll. Sci. Imp. Univ. Tokyo, vol. xviii, pt. vi, p. 17, pl. i, fig. 8, 1902; Chapman, Journ. Proc. Roy. Soc. New South Wales, vol. xlviii, p. 286, 1914; R. B. Newton, Reports Coll. Brit. Ornith. Union Wollaston Exped. Dutch New Guinea, vol. ii, Rep. No. 20, pl. i, p. 17, 1916.

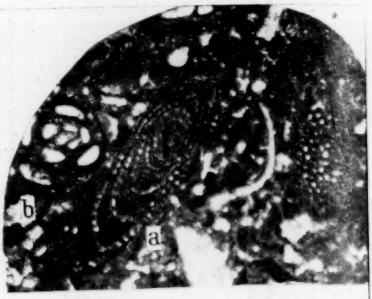
This well-known calcareous alga, first recorded from the European Miocene and so abundantly represented in the same formation as developed in Far Eastern countries, is of prolific occurrence in No. 2 pebble. Its elegant structure, well seen in Fig. 7, includes the arrangement of the rectangular tissue cells within the regularly disposed annulations of growth forming the branches. More massive forms of the genus are also present in the limestone, one being observed at the base of the section illustrated by Fig. 6*b* in close proximity to the branches that have been further enlarged in Fig. 7.

The specimen is associated with an *Alveolina* (Pl. IX, Fig. 6*a*) having a probable relationship to the Miocene *A. melo*.

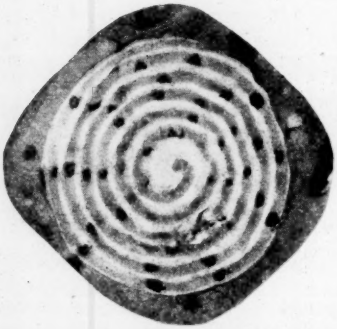
[1] "Studien über Foraminiferen aus Ost-Asien": Samml. Geol. Reichs.-Mus. Leiden, vol. ix, pp. 308–10, 1914.



1 × 10.



2 × 20.



6 × 25.

5 × 10

3 × 10.

4 × 10.

P. Dellman, photo. *R. B. Newton, direxit.*

TERTIARY FORAMINIFERA, NEW GUINEA.

Dimensions.—Rather more than 2 mm. in length.

Occurrence.—In pebble No. 2.

Distribution. — Europe and Indo-Pacific regions — Formosa, Philippines, Japan, Christmas Island, Borneo, Sumatra, Celebes, New Guinea, Australia, etc.; and of Miocene age.

Results.

The more important facts connected with the examination of the limestone pebbles prove that they may be referred to two geological horizons, viz. the Eocene and Miocene. The Eocene fossils, found in pebbles Nos. 1, 11, and 28, comprise: *Alveolina wichmanni, Laczina wichmanni, Orthophragmina* sp, and cf. *Pentellina saxorum.* The Miocene fossils, restricted to Nos. 2 and 12 pebbles, include: *Carpenteria conoidea, Alveolina* sp., and *Lithothamnium ramosissimum.*

Referring to the Eocene assemblage, it may again be pointed out that the association of *Alveolina* and cf. *Pentellina saxorum* resembles the fossiliferous contents of the "Clibs" and "Mixen" rocks of England as well as the Miliolitic limestone of Paris, which belong to the Lutetian or Middle Eocene group of the Tertiaries; hence, it is suggested that a nearly similar age may be determined for the New Guinea limestones in question.

On account of the absence of *Lepidocyclina* among the Miocene organisms, it is somewhat difficult to estimate their true geological position in that great formation. The limestones of Papua (British New Guinea) and Mt. Carstensz (Dutch New Guinea), described respectively by Mr. Chapman and the present writer, have yielded various forms of Lepidocyclines, which, studied on the basis of researches propounded by Professor H. Douvillé[1] in connexion with similar fossils from some Tertiary limestones of Borneo and the Philippine Islands, prove them to be of Aquitanian or older Miocene age. In all probability the fossils now described belong to the same stage of the Miocene, although the Nullipore *Lithothamnium ramosissimum*, it should be remembered, is particularly abundant in the "Leithakalk" of Europe (Vienna Basin), which is included in the Tortonian or youngest marine stage of the Miocene system.

EXPLANATION OF PLATES VIII AND IX.

Plate VIII.

ALVEOLINA WICHMANNI, Rutten.

Fig. 1*a*. Longitudinal section of interior. × 10.
,, 2*a*. ,, ,, ,, × 20.
,, 3, 4*a*. Internal longitudinal sections showing more regularly disposed layers than are represented in Figs. 1*a* and 2*a*. × 10.
,, 5. Longitudinal view of a weathered specimen showing the margins of successive layers and external transverse striations. × 10.
,, 6. Transverse section of specimen preserved on the polished surface of the pebble, in which the more or less equidistant apertures represent the longitudinal channels that perforate the organism. × 25.

[1] "Les Foraminifères dans le Tertiaire de Borneo": Bull. Soc. Géol. France, ser. IV, vol. v, p. 454, 1905. "Les Foraminifères dans le Tertiaire des Philippines": Philippine Journ. Sci., vol. vi, No. 2, pp. 53–80, pls. A–D, 1911.

Cf. PENTELLINA SAXORUM (Orbigny).

FIG. 1*b*. Internal section. × 10.
,, 2*b*. ,, ,, × 20.
,, 4*b*. ,, ,, × 10.

The specimens figured on this Plate are from No. 1 pebble.

PLATE IX.

LACAZINA WICHMANNI, Schlumberger.

FIG. 1. Longitudinal section. × 12.
,, 2. Transverse ,, × 12.
,, 3*a*. Longitudinal section of a compressed example. × 10.

Cf. PENTELLINA SAXORUM (Orbigny).

,, 3*b*. Internal sections. × 10.

ORTHOPHRAGMINA sp.

,, 4. Horizontal section of a fragmentary disc showing the internal characteristic rectangular chamberlets and annulations of growth. × 8.

Specimens represented by Figs. 1–4 are from No. 1 pebble.

CARPENTERIA CONOIDEA, Rutten.

,, 5. Longitudinal section of interior exhibiting the early conoidal growth, a widened base, and chambers of crescentic form. From No. 12 pebble. × 10.

ALVEOLINA cf. MELO (Fichtel & Moll).

,, 6*a*. Longitudinal view of interior. × 10.

LITHOTHAMNIUM RAMOSISSIMUM (Reuss).

,, 6*b*. Parts of branches seen in longitudinal section. × 10.
,, 7. The same, more highly magnified, displaying the rectangular cell structure of the tissue. × 25.

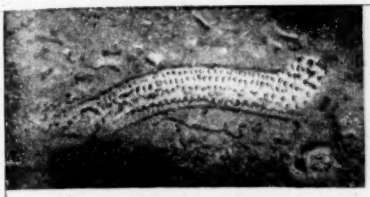
Specimens represented by Figs. 6*a*–7 are from No. 2 pebble.

III.—A NOTE ON SUBMEDULLARY CASTS OF COAL-MEASURE CALAMITES.

By E. A. NEWELL ARBER, M.A., Sc.D., F.G.S.

THE pith-casts of Calamites are common Coal-measure fossils, sometimes of use in helping to fix the horizon of certain coals. They are, however, notoriously difficult taxonomically, and in several cases there is difference of opinion among authorities both as to the essential characters of a particular type of pith-cast, and also as to what is the most nearly correct name to apply to it. Immense space is still taken up by arguments as to what, exactly, some ancient and often manifestly rough drawing, supposed to represent a type, really depicts—with a view to maintaining a strict priority as regards nomenclature. If the original specimen is now lost, as is not infrequently the case, the guessing still continues. Some workers are not content to start their synonymies chronologically with the next oldest figure, the original of which still survives and the nature of which is agreed to on all hands.

But apart from such cases, there are not a few specific names in vogue in regard to Calamite pith-casts, and also some other genera, which are purely *indefinable*. They are applied to certain fossils because there exists some, usually ancient, figure which they somewhat resemble, but if we are asked to define these species in relation



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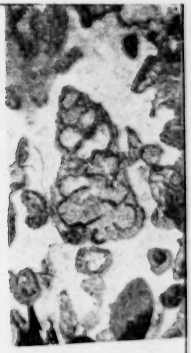

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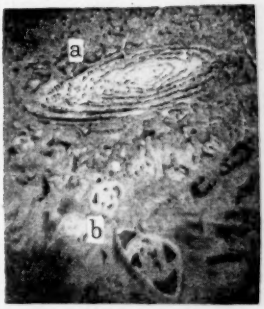

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6
× 10.

F. Dollman, photo. E. E. Newton, direxit.

TERTIARY FORAMINIFERA AND NULLIPORE, NEW GUINEA.

to other types of Calamite pith-casts we have to confess our inability to do so in strict terms.

There are a certain set of Calamite form-species which have given me much trouble in this respect, but until recently I have not understood why. It is a common observation that such specimens as I refer to here more particularly, never show the prints of the infranodal canals below the nodes. These scars in my experience offer one of the best, if not the most satisfactory, means we have of discriminating between form-species among pith-casts, considered, of course, in conjunction with other morphological features. I have, however, now realized that these specimens are not, strictly speaking, pith-casts at all. They represent incrustations of surfaces which lay external to the pith, and I propose to distinguish them as submedullary casts. In such cases the tissues appear to have undergone more or less considerable decay before the cast was formed, no doubt to an extent which varied greatly in different cases. The result has been that a cast has been formed of the medullary rays and bundles at a level which lay external to the true pith-cavity and the openings of the infranodal canals into that region.

I first realized this fact from a study of a slightly tangential section [1] of the wood of a petrified stem of a Calamite, passing through a node, in my friend Dr. Scott's collection. Part of this section is figured by Dr. Scott [2] in his *Studies in Fossil Botany*, so I need only refer to it briefly here. At this level the so-called "infranodal canals" consist of solid masses of tissue, which would leave no print, on the cast. It is only the somewhat expanded terminations of the canals projecting into the pith-cavity which gives rise to the well-known scars.

This section of Dr. Scott's appears to me to throw a flood of light on such frequently quoted and figured species as *Calamites cannæformis*, Schlotheim, 1820; *C. pachyderma*, Brongn., 1828; *C. approximatus*, Brongn., 1828 (*non* Schlotheim); *C. varians*, Sternberg, 1838; *C. Schützei*, Stur, 1881; and *C. Schatzlarensis*, Stur, 1887.

These specimens are often characterized by the coarseness of the ribbing of the internodes. There are, for instance, in the Sedgwick Museum, Cambridge,[3] several examples of large Calamite casts from the Dogtooth Rake Ironstone, Chesterfield, with ribs 5–6 mm. broad, without any trace of infranodal canals. These appear to correspond very closely to the *C. pachyderma* of Brongniart, and they are clearly submedullary in origin. *C. Schatzlarensis* of Stur appears to be a name founded on several different types of pith-cast, and the same is true of that author's *C. Schützei*.

C. varians, Sternb., is also indefinable, and nothing is gained by transferring *C. approximatus*, Brongn. (*non* Schlotheim) to Stur's species *C. Waldenburgensis* (as has recently been suggested by Kidston) or to an entirely new species, *C. Schützeiformis*, forma *Waldenburgensis*,

[1] No. 897.
[2] 2nd ed. (1908), p. 27, fig. 8; see also pp. 47–8.
[3] Nos. 439–41, 478.

as recently adopted by Kidston and Jongmans.[1] All of these submedullary types I now regard as, strictly speaking, indeterminable specifically. If any one of them has any claim to be recognized, despite the absence of infranodal scars, it is *C. approximatus*, Brongn.

IV.—Note on the Occurrence of the Zone of *A. quadratus* (Sub-zone of *Offaster pilula*) near Inkpen, Berks.

By Herbert L. Hawkins, M.Sc., F.G.S., Lecturer in Geology, University College, Reading.

ALONG the narrow belt of Upper Chalk that forms the northern margin of the Vale of Ham (or Shalbourne), a sunken and picturesque lane passes from the village of Inkpen in a direct line to Shalbourne. At a distance of about a quarter of a mile west of the cross-roads in the village (and about the same north-west of the church), the 500 ft. contour crosses this road. On the new series Survey map (Sheet 267) a quarry is marked on the northern side of the road near this point, and a northerly dip of 25° is recorded. The quarry is now almost completely grassed over, but about 100 yards to the east of it (practically on the line of the shaft of the arrow on the map) there is an open road-cutting, giving access to the Chalk, on both sides of the road.

The Chalk is much crushed, and full of small dislocations, but the northerly dip is still quite clear. A few scattered flints occur in it, but no continuous layers. Fossils are exceedingly scarce—indeed, I have paid several visits to the exposure and hitherto failed to find anything zonally distinctive. All organic remains are either already in fragments, or collapse at any attempt to extract them.

A recent visit to this unpromising section has, however, yielded evidence of considerable interest. In a block of the Chalk that had, for some local reason, escaped the worst degree of compression, three fossils occurred, which, though fragmentary and friable, are unmistakable. They are *Offaster pilula* (a small form, just like those from Kintbury, 2½ miles to the north-east); a very small, pyramidal, flat-based *Echinocorys*, whose proportions, so far as they can be determined, are exactly those of forms from the *O. pilula* sub-zone; and a primary interradial of *Stauranderaster bulbiferus*, which is fully as large as the *Offaster*. Spencer has shown that this species attains its maximum size in the sub-zone of *O. pilula*. Such an assemblage admits of but one interpretation. The sub-zone of *O. pilula* is here present. The fossils came from the section on the south side of the road, and, though absolutely no traces of fossils have as yet appeared on the northern side, there can be no doubt that the whole cutting is made in this sub-zone.

According to the geological map, the section occurs about midway between the Chalk Rock and the Tertiary border, so that, unless a strike-fault occurs to the north of the road (which is quite possible), there must be a very considerable thickness of the *quadratus*-zone developed.

[1] Kidston & Jongmans, Mededeel. Rijksopspor. Delfstoff, No. 7, vol. i, pt. i, p. 101, 1915-17.

Treacher and White (Proc. Geol. Assoc., xix, p. 385, 1906) identified the *Uintacrinus* sub-zone south-west of Kirby House (to the east of our section), and again at Prosperous Farm (about the same distance to the west). In both of these instances the exposures were, if anything, nearer to the Tertiary boundary than the roadside section. Thus it seems probable that the outcrop of *quadratus*-chalk here is of the nature of an outlier, precisely similar to the one that the above-named authors record at Laylands Green, Kintbury.

There are now three patches of this zone known to occur at the western end of the London Basin, namely, Boxford, Kintbury, and Inkpen. It can hardly be an accident that all three occur in an almost perfectly straight line, which has a north-east to south-west trend. It is true that the Boxford outlier is associated with peculiar lithological conditions and great attenuation of the zones, but in the case of the two more southerly outcrops there is no such peculiarity. On the present evidence it seems reasonable to postulate the existence of a pre-Tertiary syncline along this line, with, perhaps, a parallel complementary anticline on the eastern side which is responsible for the Hampstead Marshall inlier.

V.—The Causes of Mountain-Building.

By Harold Jeffreys, M.A., D.Sc.

An article by Mr. R. M. Deeley in the Geological Magazine for March, pp. 111–120, is mainly devoted to an attempt to find a cause of mountain-building more potent than the compression due to cooling, of which he says that "many physicists . . . are quite satisfied that it is not capable of accounting for the amount of compression required". The only physical argument he quotes in support of this statement is that of Osmond Fisher, which he may therefore be presumed to consider the most conclusive; yet it is certain that no physicist would now admit that Fisher's reasoning has any validity. It rests entirely on Kelvin's theory of the cooling of the earth, which has had to be completely revised on account of the discovery of the extensive distribution of radio-active matter in the earth's crust. The time available has been found to be about twenty times greater than on Kelvin's theory, and the cooling has therefore had time to extend to a much greater depth and to produce accordingly a very much greater compression. Our present knowledge indicates that the compression has been enough to shorten the circumference of the earth by from 133 to 227 kilometres, according to the precise distribution of radio-active matter assumed. The level of no strain is at the same time found to be at a depth of about 80 kilometres, so that the crust-movements due to compression would extend to a considerable depth.

Mr. Deeley next states that the compression required to make the Alps would be 1,050 kilometres, and deduces, apparently by a simple division by π, that the diameter must have decreased by about 334 kilometres, which he says is greater than can possibly be

allowed. Now it is obvious that such a contraction, if it occurred, would shorten *every* diameter of the earth by this amount, and could therefore raise a mountain chain as high, as broad, and as complicated as the Alps, and extending most of the way round the earth, whereas the estimate in question refers only to a chain some 1,000 kilometres in length. This simple method of evaluating the contraction needed to produce a single range is evidently unsatisfactory; what we really need to determine is the reduction, not in breadth, but in area, if the aggregate contraction needed to raise all the mountains of the earth is to be found. Taking the Rockies and the Coast Range in California as standards, according to the breadth of the particular range considered, and assuming the lateral compression to be proportional to the mean height above the surroundings (which would be exactly true if the contortion in all ranges was geometrically similar and on a scale proportional to the height), I have indicated elsewhere that all the known mountain ranges could probably be produced by a contraction in circumference of some 70 km., only about half of that shown to be available. This will, of course, have to be revised continually as direct geological information about the larger ranges, especially those in Asia, becomes available; it will further have to be increased to allow for suboceanic mountains and old ranges now almost denuded away. At the same time the estimate of the compression that could be produced by cooling may need to be increased, as the coefficient of expansion may increase more rapidly near the melting-point than I assumed; in any case the available compression and that needed to account for mountain-building are of the same order of magnitude, and a categorical statement that the theory is inadequate is clearly unjustified.

The theory of compression is complicated by the effects of denudation. When a mass of radio-active matter is removed from the surface of a continent, matter at a considerable depth is enabled to cool more rapidly in comparison with the average over the whole earth. In consequence it tends to contract more, and thereby increases the curvature of the outside, just as a bow becomes more curved when the string is tightened; the effect of this would be to raise the continents considerably. Similarly, the ocean beds would be depressed on account of the radio-active sediments acting as a blanket. A definite limit must of course be imposed on these effects by the weakness of the crust; thus the elevation and lowering could never become much greater than was necessary to give isostatic compensation, and afterwards more mountains would be raised within the continents and fewer on the ocean bed.

The alternative hypothesis offered is that crust movements have occurred owing to heavy matter sinking into lighter matter below it and causing it to spread out horizontally. This is physically quite possible, but it is difficult to see how the heavy matter could have got to the top in the first place except by compression. Isostatic readjustment, subsequent to denudation, might easily produce gentle anticlines and synclines, but the violent contortion implied by the structure of the great mountain ranges seems difficult to account for

by means of the widespread movements that one associates with such readjustment. This hypothesis, while doubtless an important secondary agency, can therefore scarcely be regarded as giving the primary cause of the formation of the great mountain chains.

A digression in the meanings of the terms *rigidity*, *plasticity*, *viscosity*, and *fluidity* may not be out of place here. When a body is exposed to a tangential or shearing stress (such a stress, for instance, as would exist if a rectangular block of wood had one face rigidly fixed and a tension were applied in the plane of the opposite one) it ordinarily changes its shape to some extent. The ideal type of substance described as *perfectly elastic* will spring back completely and immediately to its original shape when the stress is removed (the complication due to inertia being ignored). In ordinary substances, however, the recovery may be incomplete, gradual, or absent. If it occurs at all, the substance possesses *elasticity*, and the *coefficient of rigidity* is measured by the ratio of the stress to the reduction of strain when the stress is released. If it is absent, so that the body retains the shape it had just before the release, the substance is a *fluid*. Thus a fluid is a substance with no elasticity. One of its properties is that when a constant tangential stress is applied for some time it goes on changing its shape or flowing at a constant rate; the viscosity is measured by the shearing stress needed to cause flow at a certain definite rate. When the viscosity is zero, the substance yields completely and instantly to any shearing stress, however small; such a substance is a *perfect fluid*.

Substances possessing any elasticity are called solids. Imperfection of elasticity in a solid may be shown by the recovery after stress being partial or gradual. If it is partial, we see that the body has undergone a permanent change of shape, called *permanent set*; such a substance is called *plastic*. Suppose now that a certain stress F applied for a certain time T causes a permanent set of amount s, where s may be small. If the body is then stressed again by the same amount and for the same time and released, it will have acquired a further permanent set s, making $2s$ in all. Repeating the process n times will give a set ns. Now a constant stress F would naturally be expected to produce at least as great an effect in the same time as an intermittent one; hence a stress F applied for a time equal to the sum of nT, and the times when there was no stress would produce a permanent set not less than ns. This can be made as great as we like by making n great enough; hence a plastic solid can be made to change its shape as much as we like by applying a constant stress for a long enough time. In this respect it therefore resembles a viscous fluid.[1]

[1] Mr. Deeley suggests that the repetition of the stress would not give the same set each time, but a smaller one, leading to a convergent series which could never exceed a certain small amount. This implies that when a body has been strained beyond the limits of recovery it is stronger and more difficult so to strain again. The contrary seems more probable, and agrees with the phenomena of malleability and ductility, which are inconsistent with Mr. Deeley's hypothesis. Clay can undergo an indefinite amount of permanent set, and if the stress needed to give it a definite increase of set

On the other hand, the recovery after stress may be slow, though after a long enough time it may become complete. This phenomenon is the *elastic after-working*. It does not lead to permanent set or to indefinite flow when a constant stress is applied, and must therefore be distinguished from plasticity, even though the same substance may possess both properties. There are then two distinct kinds of imperfection of elasticity, and the question is further complicated by the fact that both are functions of the stress and of the previous history of the body, some substances behaving as if perfectly elastic for small stresses and very imperfectly so for large ones. For instance, suppose a weight laid on a flat surface of wet clay, which may be regarded as plastic. It will proceed to sink in, the clay acquiring permanent set, but after a time the stresses will become too small to cause set, and the weight will cease to sink, though appreciable shears still exist.

The distinctions between these various properties are of fundamental importance in all questions dealing with the behaviour of rocks under stress. The idea of plasticity, in particular, must always be carefully distinguished from smallness of rigidity. If two similar pieces of quartz and copper, for instance, are exposed to the same stress, the quartz will yield more; but when the stress is released the quartz springs back all the way, while the copper does so only partially. Thus copper is more plastic than quartz; on the other hand, the change of strain caused instantaneously by the same change of stress is less in the copper, which is therefore more rigid. In geophysical investigations the fact that a very rigid substance may also be a plastic one is continually coming into notice.

In geological upheavals and readjustments elastic after-working is probably of small importance, as the times involved are much longer than those needed for the relaxation of the strain. The importance of plasticity on the other hand is very great, for solid substances may easily flow to a great extent when a lapse of time of the order of a geological period is available, without the flow producing any noticeable effect when earthquake waves or tides are considered, so that for these movements the earth may behave as if perfectly elastic. Elastic after-working acts in the opposite direction, for if a stress is varying rapidly there will never be time for the strain appropriate to it to be produced, and consequently short period transverse waves cannot be transmitted for any considerable distance. It would thus produce a greater effect on earthquake waves than on vibrations of longer period, and we may therefore infer from their transmission that it is not appreciable in the crust of the earth. The remarkable effects of high pressure and temperature on the elastic properties of solids indicate, however, that it would be dangerous to deny on this ground its possible importance in the centre of the earth. It is certain that no great part of the earth is fluid, for it has been shown by Love that the yielding of the

increased beyond all limit, as Mr. Deeley supposes, it would obviously be impossible to model it by hand. Non-ductile substances break when the set becomes great enough, and after this occurs the series will diverge rapidly instead of converging.

crust would then prevent oceanic tides from reaching any noticeable size; earthquake waves could not be transmitted through the fluid portions; further, isostasy would be perfect, which is not the case. Below the layer of compensation, at a depth of probably some 300 kilometres, there is a layer of weakness known as the "asthenosphere", where flow appears to be produced much more easily than in the outer portions and most of the isostatic adjustment takes place. The properties of earthquake waves nevertheless show that it is very rigid.

The laws of *elastico-viscosity* and *firmo-viscosity* that I have used in previous papers are precise mathematical expressions of particular types of plasticity and elastic after-working respectively.

In the above discussion nothing has been said about the mechanism that causes imperfection of elasticity, and the argument is independent of this. Barrell believes that adjustment in the asthenosphere takes place by progressive local melting or solution under shear; the melted parts immediately flow till the shear is reduced to zero, and thus the shears are always kept small. In crystals it may take place by sliding on the cleavage planes; such bodies as pitch may be deformed by molecular displacement without anything resembling fracture; brittle substances may be crushed to powder and then spread out by the stress; but in any of these cases the recovery after the stress is removed is incomplete and the general description of plasticity applies. Elastic after-working is to be attributed to intermolecular friction.

Mr. Decley discusses at much length the question whether the liquid and solid states pass into each other continuously or discontinuously. The sudden change from one to the other at a definite temperature is a characteristic property of pure substances; the impure aggregates with which geologists have for the most part to deal may be expected to pass through a pasty state when heated, in which flow becomes steadily more easily produced. The question is not, however, a vital one; there is little liquid within the earth, and when it does occur it is probably produced, not by heating, but by local release of pressure. Most of the interior is probably at a higher temperature than the melting-point of ordinary rocks at ordinary pressures, and is only kept solid by the high pressures there existing. A local fracture would release this and render melting possible.

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REVIEWS.

I.—The Geology of the Country around Bournemouth. Explanation of Sheet 329 (New Series). Memoirs Geological Survey England and Wales. Second edition. By H. J. Osborne-White, F.G.S. pp. vi + 79. London, 1917. Price 2*s*. net.

THIS memoir, which is published as a second edition, is really a new book. The first edition, written by Mr. Clement Reid, was very brief, as it was intended at the time to publish a general memoir on the Hampshire Basin. This not being possible, a second edition of the sheet memoir has been issued in which the geology of the district is fully described. The book is written in an interesting manner; a chapter is devoted to each series of rocks, and is made up of a general section followed by more detailed description of the particular exposures. In the general sections the geological history of the district is clearly brought out. The oldest rock in the area covered by the map is the Upper Chalk. At the close of Cretaceous times the district was uplifted and denuded, and the Reading Beds rest on a surface which shows well-marked evidence of erosion. These beds are of freshwater origin. The London Clay, which follows them, is of the sandy type showing shallow-water conditions, and is becoming thinner to the west. The Bagshot and Bracklesham Beds are classified according to the old plan and not according to that proposed by Mr. Gardner, owing to the difficulty of separating the pipeclays and sands of Corfe and Poole from the Bournemouth freshwater series in the inland exposures. These show a shoaling of the water culminating in the Bournemouth freshwater series.

Throughout Bracklesham time the water became gradually deeper, and the Barton Clay shows true marine conditions. This was followed by another shallowing of the water as shown by the Barton Sands, and the highest Tertiary rocks in the area, the Lower Headon Beds, are deltaic in character. From evidence obtained elsewhere the Oligocene sea must have spread over this region, but the deposits have all been removed. The only record of Miocene or Pliocene times in the district is the slight flexuring of the strata, which must correspond to the more violent movements observed in the Isle of Purbeck and the Isle of Wight.

The Pleistocene deposits are well represented. Gravels are found at many different levels, and have been divided as follows: high plateau, 300 ft.; highest terrace, 200 ft.; Eolithic terrace, 150 ft.; Palæolithic terrace, 100 ft.; Bransgrove terrace, 60–80 ft.; Valley gravels on the valley floors from 30 to 40 ft. above O.D. These all consist of subangular flints and quartz sand, and have been laid down in running water. No organic remains have been found, but implements of Chellean and Acheulian types have been found in the Palæolithic terrace. The rivers which deposited the older of these gravels probably drained into the "Solent River", which was a continuation of the Frome, and whose valley was not breached by the sea till after the deposition of the Bournemouth plateau gravel. The character of these plateau gravels, when compared with that of the modern alluvium, shows that the volume of water in the ancient

rivers must have been very much greater then than it is now. The Palæolithic terrace of the Avon Valley is contemporaneous with the Goodwood raised beach, and bears the same relation to it as the modern alluvium does to the present beaches.

The recent alluvium contains beds of peat and submerged forests which point to a small submergence in recent times; this is also borne out by the form of the coast in Poole and Christchurch harbours. The district is not rich in economic deposits. A little iron has been worked and alum manufactured from alum shales, but the only deposits now being worked to any extent are clays in the Reading Beds, the London Clay and the Bagshot Beds which are used for pottery.

W. H. W.

II.—Flora of the Carboniferous of the Netherlands and Adjacent Regions. Vol. I: A Monograph of the Calamites of Western Europe. By Dr. R. Kidston and Dr. W. J. Jongmans. Text, Part I, 1917; Atlas of 158 plates in 4to, with Provisional Explanation of Figures, 1915. Mededeelingen v. d. Rijksopsporing v. Delfstoffen, No. 7. Gravenhage.

BY undertaking the publication of this large and exhaustive monograph, of which only the first part lies before us as yet, the Dutch Government has performed a signal service to Palæobotany. It is in every way entitled to take rank beside the classic memoirs of Zeiller and Renault on the fossil floras of the French coalfields, which are likewise Government publications. Most unfortunately, although Britain is the richest country in Europe as regards Coal-measures, no such publications have as yet been undertaken by our Government, and in this respect we are far behind other nations.

The present volume relates to the genus *Calamites* alone. Dr. Kidston and Dr. Jongmans, who are together responsible for it, have had quite an exceptional experience of these fossils, and either the one or the other has, we believe, actually studied practically every example of these plants which has been figured by previous authors, except in a few cases where the types appear to have been lost. They have also refigured here many of these specimens, and thus cleared up many points which remained uncertain when we had to rely on the original figures, which were often imperfect or indeed inaccurate representations of the fossils in question. Both the text and plates are thus exceptionally authoritative. The latter consist of 158 large quarto sheets in collotype, and there are eighty text-figures in addition. Some of the plates are, however, identical with those of a smaller atlas published by Jongmans and Kukuk in 1913. The illustrations are particularly clear and well chosen.

At present the atlas covers a somewhat wider field than the text, for owing to the War only the first part of the latter has so far been published.

The outlook here is systematic rather than morphological. The strength of the treatment adopted lies in the perfection of pure

synonymies, and in the description of particular specimens. In this respect the revision of the genus is exceptionally thorough. The 207 quarto pages are devoted to 47 species (neglecting varieties) of Calamite stems, of which 41 are of Upper, and 6 of Lower Carboniferous age. Nine of these are new names, and the number of species here first recorded from Britain is a remarkable feature of the work.

Certain names well known and in constant use are changed on what appear to be slight grounds. Thus *C. ramosus*, Art., becomes *C. carinatus*, Sternb.; while it is proposed to replace *C. approximatus*, Brongn. (*non* Schloth.), by the cumbersome term *C. Schützeiformis*, K. & J., forma *Waldenburgensis*, K. One cannot help feeling that but little is gained while not a little is lost by such modifications, however defensible they may be made by an appeal to the laws of strict priority of nomenclature.

We also find an omission of even a bare mention of all petrified material of Calamite stems, in which the anatomical structure is preserved, which strikes us as unfortunate in the case of a work professing to be a monograph of a genus.

In conclusion, we hope that our authors may soon be able to resume the publication of this valuable systematic work. If in future parts they could give us, in addition to the purely systematic side, a fuller morphological account on a comparative basis of the members of each genus, our indebtedness to them would be still further increased.

E. A. N. A.

III.—The Radioactivity of some Canadian Mineral Springs. By J. Satterly and R. T. Elworthy. Canada, Dept. of Mines, Bull. No. 16, 1917.

THE discovery of the radioactivity of mineral waters—in the case, for example, of the springs of Bath—confirmed the belief, long held, that the specific virtues of many spring waters were due to some factor other than the dissolved salts they were known to contain. The therapeutic value of radioactive waters lies in the increased activity of all the processes of nutrition and metabolism which they bring about, in the stimulated growth of red blood-cells, and in the elimination of toxins. Radioactive waters (or gases escaping from such waters) have thus a high economic value, and the Canadian Department of Mines has therefore caused to be carried out a systematic examination of a large number of springs in Ontario and Quebec and of a group of hot springs at Banff, Alberta. The results are contained in this memoir, together with a general account of radioactivity, its measurement, and its medicinal value.

None of the Canadian springs contain as much radium as those of Bath. The amount found by Sir William Ramsay in the Bath Springs was $138{\cdot}7 \times 10^{-12}$ grams per litre, whereas the highest amount found in Canada is 46 in the same units. Two other springs have 25 and 23·5 units respectively, while the others average less than 3 units (the value for sea-water is 1 unit). These figures refer to

waters that are *permanently* radioactive, since they contain radium salts in solution. In addition to this, however, there is a *temporary* radioactivity, due to the presence in solution of the short-lived gas radium-emanation picked up from the formations through which the water has passed. In this respect the Alberta springs are by far the most valuable, though the actual figures still fall below those for Bath and Buxton. The report is illustrated with a map showing the situation of the springs investigated and with twenty-one photographs of the springs themselves.

ARTHUR HOLMES.

IV.—METAMORPHISM AND ITS PHASES. By R. A. DALY. Bull. Geol. Soc. Am., vol. xxviii, pp. 375–418, 1917.

PROFESSOR DALY has written a paper on the use and meaning of the term *metamorphism*, and on the classification of the various processes which give rise to metamorphic rocks, for which all students of geology may well be grateful. The definition advocated by the author is as follows: *Metamorphism is the sum of the processes which, working below the shell of weathering, cause the recrystallization of the original crystalline materials in rocks (with or without chemical reactions) or the crystallization of original amorphous materials in rocks, the change in each case not being accompanied by a general melting of the rock or by general simultaneous solution of its constituents.*

All weathering processes are thus cut out, for their inclusion (an attempt at which has been made by Van Hise and more recently by Leith and Mead) leads to a gigantic subject of unmanageable proportions, and one for which the term *metamorphism* ceases to have its restricted, and therefore most useful, traditional significance. Volatilization is also excluded, examples of this type of transformation being the change from mud to shale, or lignite to coal, and coal to anthracite. Daly's definition, however, does not clearly distinguish between alteration processes of exogenetic origin and those of endogenetic origin, for some cases of cementation, of recrystallization of limestones by phreatic waters, and of metasomatism by descending solutions, are clearly included as examples of metamorphism according to Daly, although they may be indubitably the result of exogenetic processes. It seems to the present writer, following the lead of Mr. T. Crook, whose paper on the genetic classification of rocks (*Min. Mag.*, vol. xvii, p. 55, 1914) is one of the most illuminating recent contributions to petrology, that the term metamorphism should be still further restricted so as to exclude *all* alterations due to exogenetic processes.

The classification of metamorphic processes suggested by Daly is as follows:—

A. REGIONAL METAMORPHISM (not caused by eruptive bodies).
  I. STATIC METAMORPHISM (organic movement not a causal condition).
    1. (Temperature low) *Stato-hydral* or *hydro* metamorphism.
    2. (Temperature high) *Stato-thermal* or *load* metamorphism.

II. Dynamic Metamorphism (orogenic movement a causal condition).
1. (Temperature low) *Dynamo-hydral* or *slaty* (?) metamorphism.
2. (Temperature high) *Dynamo-thermal* or *friction* metamorphism.

III. Dynamo-static Metamorphism (*load* metamorphism in rocks lying beneath overthrust masses).

B. Local Metamorphism (caused by eruptive bodies).
I. Contact Metamorphism (magmatic influence in control).
II. Load-Contact Metamorphism (combination of load and magmatic influences).

To discuss the merits of these subdivisions would demand more space than it is permissible here to take up, and those who are interested will find a vigorous stimulation to thought in the paper itself. Whether or not one agrees with all of Professor Daly's proposals, one may at least congratulate him on an earnest and valuable attempt to reduce a subject of extreme difficulty from a state of comparative chaos to one of at least theoretical order and system.

Arthur Holmes.

V.—Genetic Classification of Underground Volatile Agents. By R. A. Daly. *Econ. Geol.*, xii, p. 487, 1917.

THE author proposes and discusses the following classification :—

A. Magmatic or Hypogene (includes volcanic and plutonic).
I. Juvenile (primitive, virgin, original-magmatic).
(*a*) In liquid magma.
(*b*) In crystallized igneous rocks and minerals, as occlusions, solid solutions, and chemical compounds.
(*c*) *Expelled*, from magma or igneous rock by crystallization or heat; may remain free or go into solid solution or new chemical compounds.
II. Resurgent (secondary-magmatic).
(*a*), (*b*), and (*c*) as above.

B. Epigene or Epigeal (includes underground atmospheric and marine water and associated gases).
I. Seepage (fresh or marine waters of infiltration).
1. *Vadose* (above the water-table).
2. *Phreatic* (below the water-table).
(*a*) *Arrested* (free, occluded, in solid solution, or in chemical combination).
(*b*) *Migrating*, because of gravity, the earth's general heat, the heat of orogenic crushing, or the heat of igneous intrusion.
II. Connate (fresh or marine waters buried with sediments or surface volcanics).
(*a*) *Stagnant* (free, occluded, in solid solution, or in chemical combination).

(*b*) *Expelled*, by diagenetic settling, crystallization during metamorphism, orogenic stress, the earth's general heat, the heat of orogenic crushing or metamorphic changes, or the heat of igneous intrusion.

C. Mixed Types.

VI.—On the Geology of the Alkali Rocks in the Transvaal. By H. A. Brouwer. *Journ. Geol.*, xxv, p. 741, 1917.

AFTER giving a general summary of what is known of the igneous complex of the Bushveld, the author deals with the special types of alkali rocks that occur in the Pilandsberg and Leeufontein, and west of Lydenberg. He suggests that the nepheline syenites and allied rocks were derived from a residual magma left after the differentiation from the parent magma of ultra-acid rocks containing as much as 97 per cent of SiO_2. Not only was the residual magma enriched in alkalies and alumina relative to silica, but it also contained a concentration of fluorine and other volatile fluxes. Much more work, however, is needed in this region before either the age of the complex or the genetic relations of its multitude of rock types can be accurately determined.

VII.—The Geological Features of the "North End", Kalgoorlie. By F. R. Feldtmann. Bull. Geol. Surv. Western Australia, No. 69. pp. 152, with 43 figures and an atlas of 14 plates. Perth, 1916.

THE area dealt with in this memoir comprises about 2¼ square miles. It is composed almost entirely of old and highly altered igneous rocks, which can be divided into two main groups, the older and younger greenstones. The older greenstones were originally a large series of basaltic flows, and cover the greater part of the surrounding region. Along a line of weakness striking N.N.E.–S.S.W. in these older rocks a series of dykes, the younger greenstones, were intruded. These show a gradation from basic to more acid composition, and include types ranging from dolerites to albite porphyrites, the latter being the last of the succession. At different times during the intrusion of these dykes the district was subjected to intense pressure in an east and west direction, which resulted in the amphibolitization of the igneous rocks and the production of shear zones and thrust faults. The period of most violent pressure took place after the intrusion of the albite porphyrites.

Very shortly after this siliceous solutions with vapours of boron, sulphur, and hydrocarbons, or oxides of carbon, were forced along the shear zones, with the formation of jaspers and graphitic schists. These were followed by the gold-bearing solutions. They formed several different mineral deposits; quartzose and schistose lodes along the strike of the dykes and cross quartz veins striking more or less at right angles to the dykes. The auriferous lodes seem to be genetically connected with the albite porphyrites, and occur most frequently in the neighbourhood of these rocks along the major

shear zones. They are, however, found all through the younger greenstones and even in the older greenstones. In these rocks they are accompanied by bleaching of the walls of the lode, owing to the breaking down of the ferro-magnesian minerals with the formation of pyrites.

Both lodes and cross veins carry gold in payable quantities, and both are worked in the mines. The workings have, up till now, been confined chiefly to the oxidized zone, and have not anywhere been carried far below it owing to the increased difficulty and expense of working; they are, however, now being pushed further down.

The memoir gives a short description of the individual mines and is illustrated by many figures and photographs, and is accompanied by an atlas of large-scale geological maps on which all the details of the structure are shown.

W. H. W.

VIII.—The Cretaceous Faunas of the North-Eastern Part of the South Island of New Zealand. By Henry Woods, M.A., F.R.S. New Zealand Geological Survey, Palæontological Bulletin No. 4. pp. i–viii, 1–42, pls. i–xx, text-figs. 1 (map) and 2 (section).

THE fossils described in this work have been collected from two series of beds. The one, occurring in the neighbourhood of the Clarence River, south of Blenheim, yields a fauna characteristic of the Lower Utatúr Group of Southern India. This fauna, which has been recognized also in Zululand, Madagascar, Australia, Japan, Queen Charlotte Island, Peru, and California, is approximately Albian in age; and it is of interest that *Inoceramus concentricus*, so characteristic of the English Albian, is found in the corresponding New Zealand deposits. The other series of beds, occurring in the neighbourhood of Amuri Bluff, north of Christchurch as well as around Christchurch itself, and south of the localities for the Utatúr fauna, is of Upper Senonian age and passes upwards into the Eocene. The lower portions of these beds produces an Upper Senonian fauna comparable with that occurring in the Ariyalúr Beds of Southern India, in Madagascar, in the Umzamba Beds of South Africa, in Japan, Vancouver, Chile, Southern Patagonia and Graham Land.

The forms described from the lower fauna include two new species of *Trigonia*, one of "*Modiola*", one of *Lima*, one of *Aucellina*, one of *Panopea*, and a new variety of *Inoceramus concentricus*. From the higher fauna one new species of *Nuculana* is described, one of *Malletia* (*Neilo*), one of *Barbatia*, one of "*Arca*", one of *Cucullæa*, one of *Pectunculus*, one of *Trigonia*, one of *Pecten* (*Camptonectes*), one of *Pecten* (*Æquipecten*), one of *Lima* (*Limatula*), two of *Inoceramus*, one of *Astarte* (*Eriphyla*), one of *Anthonya*, one of *Lucina*, one of *Cultellus*, two of *Callista* (*Callistina*), one of *Panopea* and one of *Thracia*.

The figures contained in the twenty plates are collotyped from brush-drawings by T. A. Brock, and maintain the level of excellence that one has come to expect in his work since the publication of his

drawings in Mr. Woods' Monograph on Cretaceous Lamellibranchs. The plates, moreover, have already had a history; for the original issue, we are told in the introduction, was lost in the wreck of "Tongariro" off the New Zealand coast in August, 1916. They were reprinted from the original blocks, and the Bulletin finally appeared in 1917.

IX.—Brief Notices.

1. The Active Volcanoes of New Zealand. By E. S. Moore. *Journ. Geol.*, xxv, p. 693, 1917.

THE author describes the five active volcanoes of New Zealand lying along the Whakatane fault, and discusses their relation to the later volcanic history and petrographical provinces of the islands. Mt. Tarawera and its rocks, varying from rhyolite to basalt and including pyroclasts, are dealt with in special detail.

2. Homocline and Monocline. By R. A. Daly. Bull. Geol. Soc. Am., vol. xxvii, p. 89, 1916.

THE term *homocline* is suggested as a general name for a mass of bedded rocks all of which dip in the same direction. The term *monocline* is thereby restricted in accordance with the definition first formulated by Sir A. Geikie.

REPORTS AND PROCEEDINGS.

I.—Geological Society of London.

March 20, 1918.—G. W. Lamplugh, F.R.S., President, in the Chair.

The President referred with sorrow to the death, on March 18, of Dr. George Jennings Hinde, F.R.S., who had served the Society for many years as a Member of the Council. The President also recorded the loss of Captain Lewis Moysey, M.B., R.A.M.C., who was on H.M. Hospital Ship *Glenart Castle*, torpedoed in the Bristol Channel on February 26. It was stated that the Council had sent resolutions of condolence to the relatives of both these Fellows.

The President announced that the Council had awarded the Proceeds of the Daniel-Pidgeon Fund for the present year to James Arthur Butterfield, M.Sc., F.G.S., who proposes to conduct researches in connexion with the Conglomerates and Sandstones underlying the Carboniferous Limestone Series in the North-West of England.

Dr. W. F. Smeeth delivered a lecture on the Geology of Southern India, with particular reference to the Archæan Rocks of the Mysore State. With the aid of a map, prepared by the Geological Survey of India, the Lecturer pointed out the general character of

the geological formations of Southern India, which consist very largely of a highly folded and foliated complex of Archæan gneisses and schists, followed by some considerable patches of pre-Cambrian slates, limestones, and quartzites; with these are associated basic lava-flows and ferruginous jaspers. The remaining formations consist of remnants of the Gondwana Beds (Coal-measures of Permo-Carboniferous age), a few patches of Cretaceous rocks, some Tertiary and Pleistocene deposits, and recent sands and alluvium, all situated along the coastal margins of the Peninsula. He contrasted the scanty post-Archæan record of Southern India, the apparent non-submergence of the greater portion of the area, and its freedom from great earth-movements since Archæan times, with the widely extended formations of Northern India, which recorded oft-repeated movements of depression and elevation, culminating in the rise of the Himalaya in Tertiary times and accompanied by igneous activity on a gigantic scale, as proved by the outpourings of the Deccan Trap.

In discussing the Archæan complex, the Lecturer traced the history of the various views which have been held. Newbold (1850) regarded the complex as formed of Protogene schists and gneisses intruded into by granites. Bruce Foote (1880) separated the schists (to which he gave the name "Dhárwár System") from the gneisses, and regarded them as laid down unconformably upon the gneisses and granites which, for many years thereafter, were embraced in the term "Fundamental Gneissic Complex". He regarded the Dhárwár System as transition-rocks between the old gneisses and the older Palæozoic rocks (Cuddapa, etc.). Holland (1898) differentiated the Charnockites, showing that they formed a distinct petrographical province with intrusive relations to the main members of the gneissic complex, and in 1906 he proposed to regard the Cuddapa System as pre-Cambrian, and separated by a great Eparchæan Interval from the Dhárwár System, which, together with the gneissic complex, he classed as Archæan. In 1913 Holland added a group of post-Dhárwár eruptive rocks, and produced a classification of the pre-Cambrian rocks of India which exhibits a remarkable parallelism with that given by Lawson (1913) for the pre-Cambrian of Canada.

The work of the Mysore Geological Survey from 1899 to 1914 had gradually eliminated the Fundamental Gneissic Complex, and shown that within the area of the Mysore State—representing some 29,000 square miles of the Archæan complex—the oldest rocks were the Dhárwár System, which had been intruded into by at least four successive granite-gneisses, namely: the Champion Gneiss, the Peninsular Gneiss (forming the greater part of the area), the Charnockites, and the Closepet Granite Series. If we compared this succession with Holland's 1913 classification, without assuming any real correlation with the Canadian rocks, but viewing the Dhárwár rocks as Huronian, as suggested by Holland, then his post-Dhárwár eruptive series (Algoman) included the whole of the gneisses of Mysore, while equivalents of the Laurentian and Ontarian formations were wanting. On the other hand, if the Dhárwár rocks were regarded as Keewatin, then the gneisses of Mysore might represent Laurentian and, possibly, Algoman formations, while

representatives of the Huronian would be non-existent. Obviously, therefore, the Mysore Archæan succession was either very incomplete or it did not fit in with the classifications of Holland and Lawson. It was to be remembered that Holland's classification dealt with a much wider area than Southern India, and the essential problem appeared to be whether his Bundelkhand gneiss (Laurentian) and the Bengal gneisses (Keewatin) were really older than, and unconformable to, the Dhárwár System—as represented by him—or whether they were post-Dhárwár eruptives corresponding to portions of the Mysore gneissic complex. In favour of the latter view it was noted that observers acquainted with both have appeared to recognize the Bundelkhand and Bengal types of gneisses in and around Mysore, and that all of these gneisses have, until recently, been regarded as forming part of the great Fundamental Gneissic Complex of India.

The Lecturer then described the map of Mysore, which, on a scale of eight miles to the inch (1 : 506,880), presented a simplified summary of the work of the Mysore Geological Survey. On lithological grounds the Dhárwár System was divided into an Upper and a Lower Division. The former was composed largely of basic flows and sills with their schistose representatives. Whether some of the chloritic schists, slates, phyllites, and argillites were of sedimentary origin was still doubtful. In the series as a whole, chlorite predominated and hornblende was subordinate. The presence of carbonate of lime, magnesia, and iron was a strikingly prevalent feature. The Lower Division was composed of dark hornblendic epidiorites and schists, which were distinguishable from the greenstones of the Upper Division by their dark colour and practical absence of chlorite. Many of the greenstones and schists of the Upper Division appeared to resemble Keewatin rocks of Lake Superior, such as the Ely Greenstone series (save that augite is conspicuously absent in the Mysore rocks), and it had been suggested that the dark epidiorites, which naturally crop out between the rocks of the Upper Division and the intruding gneisses, might be merely metamorphosed portions of the greenstones and chlorite-schists. This might be true in some cases, but the independent existence of the dark hornblendic rocks of the Lower Division was supported by the fact that they do not exist in many places where the gneisses come into contact with the greenstones; that many of the former retain original igneous structures, which would be unlikely to survive the chloritization and the subsequent change to epidiorite; and, finally, that the amphibolitization of the rocks of the Lower Division appears to have been complete before the intrusion of the earliest of the gneisses which, with its associated pegmatites and quartz-veins, has developed secondary augite in the hornblendic rocks along intrusive contacts.

The Lecturer referred briefly to the autoclastic conglomerates which were usually associated with intrusions of the Champion Gneiss, to the intrusive character of some of the quartzites or quartz-schists, and to the evidence that the limestones were, partly, if not wholly, due to metasomatic replacement of other rocks by carbonates of lime and magnesia.

The Dhárwár schists of Mysore contain a widely extended series of banded quartz iron-ore rocks, very similar to those of the Lake Superior district, the origin of which has been the subject of much discussion and is still very perplexing. Some of the earlier American geologists considered them to be directly igneous in origin, but these views are now discredited, and replaced by an interesting and ingenious theory of chemical precipitation from liquids associated with subaqueous lavas. The Lecturer suggested that some of these rocks might be pegmatitic intrusions of quartz and magnetite, and that some might be the metamorphosed relics of igneous rocks composed largely of highly ferruginous amphiboles (such as cummingtonite) or other chemically allied minerals.

II.—Mineralogical Society.

March 19, 1918.—W. Barlow, F.R.S., President, in the Chair.

Professor E. S. Federov: "Graphical Operations with four Independent Variables." Apropos of Bocke's suggestion of the use of multi-dimensional geometry for such operations, with special reference to the case of the chemical constitution of tourmaline, the author remarks that he had already put forward a similar suggestion, without, however, making use of imaginary dimensions. A system of points is replaced by a system of vectors, and in this way, since each end of a vector has two co-ordinates, a relation between four independent variables may be expressed graphically. Different series of vectors of the first order give rise to vectors of the second order, and they in their turn to vectors of the third order. Certain special cases were discussed.

Professor R. P. D. Graham: "Lattice-like Inclusions in Calcite, from North Burgess, Ontario." The calcite, which is almost invariably twinned about e $(01\bar{1}2)$, contains numerous fine needles, arranged parallel to the edges of the rhombohedron e, of a hydrous magnesium silicate, which chemical analysis showed to correspond to the formula $5\,MgO\,.\,6\,SiO_2\,.\,4\,H_2O$, which is usually assigned to the mineral spadaite. Since the needles are only slightly acted on by cold dilute acid, they remain behind in the form of a lattice on dissolution of the calcite. Other included minerals are pyroxene, quartz, titanite, and pyrites. The source of the solutions which supplied the magnesium silicate was discussed.

Dr. J. W. Evans: "On Linear Rock-Diagrams." The different types of linear or variation diagrams, in which the chemical constituents of different rocks are represented by vertical distances, were reviewed, and the use of modifications to indicate the probable mineral compositions was proposed. Each rock is represented by two diagrams. In the first, or alumina diagram, distances representing the molecular proportions of (1) the potash, (2) the potash and soda, and (3) the potash, soda, and lime in each rock are measured vertically upwards in succession one above the other from the base-line, and corresponding points for different rocks are connected by continuous lines. At the same times distances representing (4) the alumina, (5) the iron oxide, and (6) the magnesia are measured

on the same lines in the same manner, and are connected by continuous lines. Not only will this diagram indicate the proportions of the constituents, but also the position of the points on line (4) relative to those on lines (2) and (3) will indicate the probability of the occurrence of minerals dependent on the amount of alumina. If (4) is higher than (3), andalusite, cordierite, or mica may be expected as well as hypersthene, all the lime being converted into anorthite. If (4) is less than (3), diopside, augite, or the corresponding amphiboles will probably be present; and if it is less than (2), minerals of the ægirine type may be found. In the second or silica diagrams the lowest series of points show the amount of silica required by the bases of a rock for the formation of leucite, nepheline, anorthite, wollastonite, and olivine, the second series the additional silica necessary to form orthoclase and albite, and the third series the amount required to convert the olivine into hypersthene, while the fourth line represents the amount of silica actually present. The position of the last relative to the others will throw valuable light on the silicates that may be expected, though allowance must be made for the influence of the bases on one another. For instance, the presence of the constituents of wollastonite will call for a higher silicification of part of the olivine to form a monoclinic pyroxene or amphibole at the expense of the felspars.

III.—Liverpool Geological Society.

March 12, 1918.—J. C. M. Goveir, M.D., M.R.C.P., F.G.S., President, in the Chair.

The following papers were read:—

1. "On the Distribution and Significance of Barium Compounds in Sedimentary Rocks, with special reference to the Trias." By H. W. Greenwood.

The author had collected a large amount of statistical information as to the presence of barium compounds in the lithosphere, the oceans, and underground waters, which revealed their widespread occurrence, especially in Triassic sandstones in the form of barytes. In the latter it was noted that the barytes is apparently invariably secondary, and has found its way into the rocks by percolation and infiltration, that it occurs in both the Keuper and Bunter divisions, is richest at the surface, the quantity falling rapidly with the depth, and is commonly most abundant in the highest exposures in any one district. These facts, among others, led the author to suggest that the barium had been derived from superincumbent strata, most probably Jurassic, a suggestion which, if upheld, would make the presence of barytes a valuable index to the original distribution of the Jurassic seas.

2. "Notes on the Parallel Roads of Glen Roy." By C. B. Travis.

In this paper the author gave an extremely lucid description of these well-known natural features, based upon personal observations made during visits within the last few years.

CORRESPONDENCE.

THE PERMIAN IN THE MIDLANDS.

Sir,—Some thirty years ago when I was working in the new Red Rocks of the Birmingham district, I found that the Bunter Conglomerate invariably rested upon a Breccia with a slight unconformity. I pointed this out to the late Mr. Joseph Landon, who also found the same succession at Barr Beacon. Associated with the Breccia were deposits of sandy grit, the formation being of varying thickness. I also found—what was of much greater importance—that there was a very pronounced unconformity between them and the red clays and sandstones upon which they rested.

On April 12, 1890, I read a paper to the Vesey Club at Sutton Coldfield giving full particulars of this formation, which had never been separately marked on the Survey map, nor mentioned in the Survey memoirs, although its outcrop covered a very considerable area. At that time the red clays which cap the Carboniferous system in this district were mapped as Permian, which accounts for my reference to the breccia beds as a deposit between the "Permian" and the Bunter pebble beds. It is now, I believe, pretty generally recognized that these red clays belong to the Carboniferous system. If this be so, it gives a greatly added interest to these intermediate beds, and it comes to be a question whether they are not really the representatives of the Permian system in this district.

I was called away from the Midlands shortly after reading my paper, and have since been unable to follow up my investigations. Fortunately, however, this district has been recently re-mapped by the Geological Survey, and I had the pleasure of hearing a paper read by Mr. Cunnington at the Vesey Club in 1914, in which he confirmed my work and stated that he had found the beds in some places to reach 100 feet in thickness.

I believe the Survey are proposing to extend their researches, but my chief reason in writing this is to point out that much can be done by local geologists in carrying out a more detailed investigation in regard to these beds.

A few points I would suggest are:—

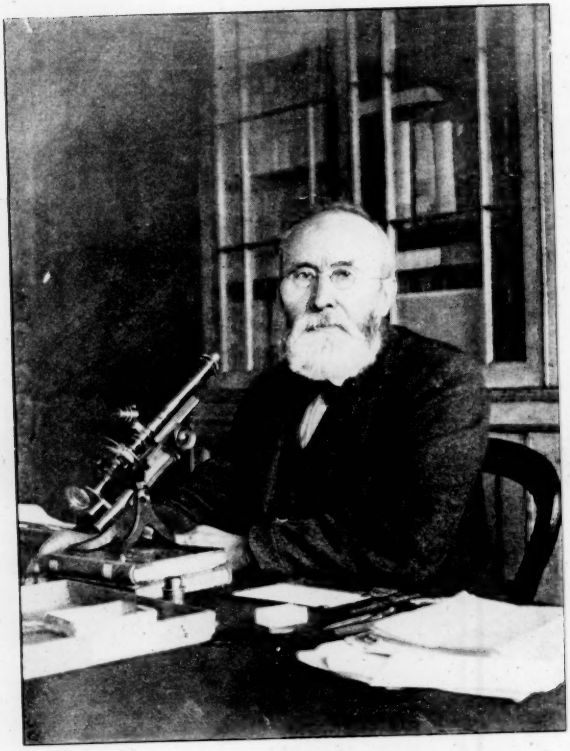
(1) Through how wide an area are they found beneath the Pebble beds?
(2) What is their thickness and constitution in different districts?
(3) Is the breccia constant in its composition?
(4) Are these beds the equivalent of the typical Permian breccias in other places, and are they on the same horizon?
(5) The upper part of the deposit in the Sutton Coldfield district is pure breccia, the grits being beneath the breccia, and the unconformity with the Pebble beds is slight. Is this the rule elsewhere?
(6) Can any light be thrown upon the source of the breccia?

And more important than all:—

(7) Do the grits contain any fossils, and what is their age?

In this way much may be done to supplement the work of the Survey, which is naturally of a more general character.

A splendid section, showing the junction of the Breccia and the Bunter pebble beds can be seen at the Black Pool Quarry at Sutton Coldfield, at the base of which at least a quarter of an acre of the



George J. Hinde.

rolling surface of the Breccia, from which the Pebble beds have been removed for road metalling, can be seen.

My personal belief is that the red clays are Carboniferous, and the breccia bed Permian.

C. J. Gilbert.

"Staghurst," Berkhamsted.
March 21, 1918.

A NOTE ON ISOSTASY.

Sir,—I am much indebted to Mr. Anderson for calling attention to the oversight in my calculation. His re-calculation is perfectly right. Consequently, instead of 1,100 feet as the possible thickness of sediment accumulated in a sea of 100 fathom depth, we have 1,872 feet; or in the improbable case of a density as low as 2·7 for the supporting column, as much as 3,000 feet. These figures are still far removed from those great thicknesses of shallow-water deposit for which isostasy has been claimed as an adequate explanation.

A. Morley Davies.

Imperial College, S.W. 7.
April 13, 1918.

OBITUARY.

GEORGE JENNINGS HINDE,

Ph.D. (Munich), F.R.S., F.G.S., V.P. Pal. Soc.

Born March 24, 1839. Died March 18, 1918.

(WITH A PORTRAIT, PLATE X.)

As a worker gleans in a cornfield after the crop has been harvested, I have endeavoured to collect some records of my friend George Hinde, whose life's work terminated in March last. He was a Norwich boy, like myself, and went to the Grammar School there, but being my junior by seven years we never met until many years later, our paths in early life lying wide apart.

George Hinde was the third son of Ephraim Hinde and grandson of the founder of the firm of Ephraim Hinde & Son, Paramatta manufacturers in that city. His father lived near his Norwich factory, but in 1847 bought a farm at Catton, where he and his family resided. George's mother died when he was 13 years old, and at 16 his father sent him to learn farming in Suffolk with a Mr. Spelman, where, being a studious lad, he spent his leisure hours in acquiring Latin, French, algebra, physics, and chemistry. About this time he heard a lecture by the Rev. Mr. Blowers on "Hugh Miller", which greatly interested him, and he bought and read Hugh Miller's books, and thus his mind was first directed to the study of geology.

When 18 years of age he commenced to farm his own land at Bawburgh, near Costessy, Norwich. Early in 1862 he attended a series of lectures in Norwich by William Pengelly, F.R.S.; these further stimulated his desire to take up geology, which later on became the leading ambition of his life. In the same year he paid

a visit to the British Museum, and from my wife's relationship to his family he claimed me as a "cousin", and so we continued to the end. This visit to the "Geological Department" seems to have acted as a loadstone which attracted him to the Museum in later years. He particularly mentions in his diary the impression made upon him by our geological talk.

In the autumn of that year he gave up his farm and sailed for Buenos Aires, and took up sheep farming; but save for a note in his diary of a geological walking tour, he does not appear to have had much spare time for scientific pursuits in South America. After some years ranching in Argentina Hinde returned home, but very soon after set out for North America, where he devoted seven years entirely to geological research, during which time his travels extended from Nova Scotia on the east to Nebraska on the west, and from Lake Superior to the Gulf of Mexico.

For a time he settled in Canada, entering himself as a student in geology under Professor H. Alleyne Nicholson, F.R.S., in Toronto University, with whom he published his first paper in 1875, "On the Fossils of the Clinton, Niagara, and Guelph Formations of Ontario" (*Canadian Journal*, xiv). He also wrote papers on "The Glacial and Interglacial Strata of Scarboro' Heights, Ontario" and "On the Occurrence of Boulders of the Calciferous Formation near Toronto". Later on he made the interesting discovery of "Conodonts" and Annelid jaws in the Cambro-Silurian of Canada and the United States.

Returning to England in 1874, he was elected a Fellow of the Geological Society of London.

He also pursued his search for Conodonts and Annelid jaws in the Silurian strata of the West of England and the Sub-Carboniferous rocks of Scotland; he found these in many localities identical with those he had obtained in North America, which he subsequently figured and described in the Quarterly Journal for 1879, 1880, and 1882.

This work and the renewal of his early study of the Chalk Sponges occupied him until 1878, when he visited Sweden, Gotland, and Denmark and travelled across Europe to Palestine.

During 1879–80 he studied under Professor Karl von Zittel in the University of Munich, and upon receiving the degree of "Doctor of Philosophy" he presented for his inaugural dissertation a paper on the "Fossil Sponge-spicules found in a flint from the Upper Chalk at Horstead in Norfolk" (Munich, 1880).

Dr. George Hinde was married in 1881 to Edith Octavia, daughter of James Clark, of Street, Somerset, of the Society of Friends.

In February, 1882, he was awarded the Wollaston Fund for his researches in fossil Invertebrata of North America and the Glacial phenomena of Canada. He was also elected a Member of Council of the Geological Society, on which he served for nearly twenty years, being made a Vice-President in 1893.

After the removal of the Geological Collections from the British Museum at Bloomsbury to the new Natural History Museum in Cromwell Road, the Trustees authorized Dr. Hinde to prepare a Catalogue of the Fossil Sponges in the Geological Department. This

was completed between 1881 and 1883, and forms an important work of reference, admirably illustrated by Miss Sutt and Mrs. Herschell (4to; pp. viii + 248, with 38 plates).

After the death of my colleague Professor John Morris, in 1885, Dr. Hinde became an Assistant Editor of the Geological Magazine, an office he held for thirty-two years to the great advantage of this journal, to which he also contributed numerous articles.

He joined the Palæontographical Society in 1886 and commenced a monograph on the British Fossil Sponges, completed in 1912. He also contributed with Professor T. Rupert Jones, F.R.S., a monograph on Cretaceous Entomostraca (1889–90). Dr. Hinde was elected on the Council in 1897, and Treasurer in 1904, an office he held for ten years. On retiring from it he was made a Vice-President in succession to Sir A. Geikie (1916).

During the meeting of the International Geological Congress in London in 1887, Dr. Hinde rendered important services on the Committee by preparing a temporary museum in the Library of the London University, and also by his knowledge of languages in acting as geological guide and interpreter to the numerous distinguished foreigners present, to many of whom he was already personally known during his extensive travels.

When the bye-laws of the Geological Society underwent revision in 1889, the question of the admission of women as "Fellows" came up for discussion. Dr. Hinde took a very active part in its support; but although Sir Joseph Prestwich and many others maintained that the time had come when, women having proved by their work their eligibility for Fellowship, the privileges of the Society should be extended to them, the proposal was defeated by a majority of four out of sixty-two Fellows voting.[1]

Dr. Hinde spent many years in active field-work, followed by strenuous work in the laboratory in the preparation of rock-sections for the microscope, and then, after much study of existing literature, came a steady flow of scientific papers, continued for nearly forty years.

In addition to the two important monographs on Fossil Sponges already referred to, the subjoined list shows some twenty additional separate papers on that class of organisms.

That on the Receptaculitidæ (including *Ischadites*, *Sphærospongia*, *Acanthoconia*, and *Receptaculites*) from the Silurian and Devonian strata of England, Belgium, Silesia, Bohemia, Gotland, Canada, and the United States, is an admirable piece of patient investigation in solving the nature of an obscure group of fossil organisms long in dispute. Hinde proved them to belong to a genus of siliceous Hexactinellid sponges, of which he defined their relations and figured their structures with elaborate detail (see Q.J.G.S., 1884).

Another example of careful and laborious work is his memoir on the *Porosphæra*, a group of small but very abundant globular

[1] The author of this memoir, when President in 1895, discussed the same subject; but although strongly advocated by many of the Fellows it still remains in abeyance.

bead-like (often perforated) organisms from the Chalk, of which (aided by Dr. Arthur Rowe) he collected no fewer than 2,900 specimens. After examination of their minute structure under the microscope he showed them to belong to a group of Lithonine Calcisponges, of which he described and figured six species (see Journ. Roy. Micr. Soc., 1903).

By the investigation of chert rocks of Lower Palæozoic age from every part of the world Hinde demonstrated their geological importance and truly organic origin, built up of millions of microscopic siliceous skeletons, often of exquisite forms, of Radiolaria. He devoted twenty papers to their description: those from the Cherts of the Dutch East Indies he collaborated with Dr. G. A. F. Molengraaff, and those of Devon, Cornwall, and Somerset, with Mr. Howard Fox, F.G.S., of Falmouth.

Of the class Annelida, the naked wandering marine worms, without hard parts (save very minute toothed jaws and spines), were formerly known only by their *tracks* upon the Palæozoic rocks; but jaws of Annelids were found by Hinde in Cambro-Silurian formations in America, Britain, Sweden, etc., often mixed, as in the Ludlow "Bone-bed", with parts of various other microscopic organisms, such as the teeth of cartilaginous fishes, *Myxine*, etc., Crustacean remains, etc. He separated many of these and figured them, and also the Annelid jaws,[1] for the first time since their discovery by Dr. Pander in Russia in 1854.[2]

In connexion with the Royal Society he communicated a paper on "Beds of Sponge-remains in the Lower and Upper Greensand Formation of the South of England", published in the *Phil. Trans.*, 1886 (pp. 493–53). He also reported to the Royal Society's Committee on Coral Reefs the result of his investigation of the organisms obtained by him from the cores extracted from the

[1] The author determined seven genera of Annelids, and enumerated fifty-five different forms.

[2] Professor Owen, Dr. Harley, and H. Woodward also drew attention to them; see "Conodonts", Murchison's *Siluria*, 5th ed., 1872, pp. 134, 356, 542, 544.

borings in a coral-reef on the Funafuti Atoll (see *Phil. Trans.* for 1904).

George Hinde was elected a Fellow of the Royal Society in 1896. In the year following the Council of the Geological Society awarded him the Lyell Medal. In presenting it the President, Dr. Henry Hicks, referred to the large experience gained by Dr. Hinde with Professor Nicholson in Toronto, and continued later under Professor K. von Zittel in Munich, which had resulted in the valuable work he had since performed that had placed him in the foremost rank of those devoted to the study of minute structures of fossil organisms.

In 1910 the Royal Geological Society of Cornwall conferred upon Dr. Hinde the William Bolitho Gold Medal "for his valuable contributions to the Geology and Palæontology of Cornwall" (partly in conjunction with Mr. Howard Fox, F.G.S., of Falmouth.

Such are the gleanings I have gathered from the scientific work of my friend George Hinde. He was essentially a keen investigator of Nature, an accurate observer, and a strenuous, untiring worker who never lost interest in his researches. He was naturally of a silent and retiring disposition—having lived much alone in his early life—a man who formed few intimacies, but had the gift of ardent loyalty to those he made his friends.

He spent much of his time latterly in his quiet home at Croydon, with his books, microscope, and specimens. After some months of ill-health, carefully tended by his devoted wife, George Hinde passed peacefully away on March 18, 1918. He leaves a family of three sons and two daughters.

HENRY WOODWARD.

LIST OF DR. HINDE'S PAPERS AND MEMOIRS.

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"On Conodonts from the Chazy and Cincinnati Group of the Cambro-Silurian, etc., in Canada and the United States": Quart. Journ. Geol. Soc., xxxv, pp. 351–69.

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1880. "Fossil Sponge-spicules from the Upper Chalk, found in the Interior of a single Flint-stone, from Horstead in Norfolk" (Inaugural Dissertation): Munich.

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"Notes on Fossil Calcispongiæ": Ann. Mag. Nat. Hist., x, pp. 185–205.

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1884. "Structure and Affinities of the Family of the Receptaculitidæ": Quart. Journ. Geol. Soc., xl, pp. 795–849.

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1887. "On the genus *Hindia*, Duncan, and the name of its typical species": Ann. Mag. Nat. Hist., xix, pp. 67–79.

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"Character of the Beds of Chert in the Carboniferous Limestone of Yorkshire": Nature, xxxv, p. 582.

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"Note on the Spicules described by Billings in connection with the Structure of *Archæocyathus minganensis*": GEOL. MAG., Dec. III, Vol. V, pp. 226–8.

"The Chert and Siliceous Schists of the Permo-Carboniferous Strata of Spitzbergen": ibid., pp. 241–51.

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